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FLIGHT PATH DISPLAYS

Debra A. Warner

BUNKER RAMO CORPORATION W.P., Ohio
4130 Linden Avenue
Dayton, Ohio 45432

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John Reising
JOHN M. REISING
Project Engineer

John D. Vrettos
JOHN D. VRETTOS, Maj, USAF
Chief
Crew Systems Development Branch
Flight Control Division

FOR THE COMMANDER

James R. Stanley
JAMES R. STANLEY, Col, USAF
Chief, Flight Control Division

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Aircraft display technology has advanced to the state where the flight path display--an integrated format on which both the vertical and horizontal path are graphically represented--is feasible. This report researches efforts made to design flight paths for use in both fixed wing and rotary wing aircraft. Results from comparison evaluations of flight path and non-flight path displays are discussed and conclusions drawn with respect to desirable display symbology. An hypothetical flight path display designed as a result of the findings in the referenced studies is proposed for future testing and evaluation.

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FOREWORD

This Technical Report is the result of a work effort initiated by the Requirements and Analysis Group of the Crew Systems Development Branch (FGR), Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio. Mr. Robert Bondurant III is the group leader and Dr. John Reising is responsible for human factors. The objectives of this report included (1) providing a flight path displays literature review to include display descriptions, design methods and strategies, and related human factors findings; (2) researching evaluative studies which measured flight (simulator) performance comparing flight path and non-flight path display formats; and (3) based on conclusions drawn from above research, proposing an integrated flight path display format for future generation and evaluation.

The Bunker Ramo Corporation performed this work on-site at AFFDL under USAF Contract Number F33615-78C-3614. The contract was initiated under Task Number 240304, "Control Display for Air Force Aircraft and Aerospace Vehicles" which is managed by Maj J.D. Vrettos, as Project Engineer and Branch Chief for the Crew Systems Development Branch (AFFDL/FGR) Flight Control Division, Air Force Flight Dynamics Laboratory.

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LIST OF ABBREVIATIONS

ADI/HSI	Attitude Director Indicator/Horizontal Situation Indicator
CCD	Coordinated Cockpit Display
CRT	Cathode Ray Tube
EADI	Electronic Attitude Director Indicator
FOV	Field of View
FPA	Flight Path Angle
GPI	Ground Position Indicator
HSD	Horizontal Situation Display
IFR/VFR	Instrument Flight Rules/Visual Flight Rules
ILS	Instrument Landing System
PFPA	Potential Flight Path Angle
PITS	Path-in-the-Sky (Display)
RMS	Root Mean Square
SVSD	Side Vertical Situation Display
VSD	Vertical Situation Display
V/STOL	Vertical/Short Takeoff and Landing

SUMMARY

The feasibility and plausibility of flight path displays have been researched with increasing interest over the past two decades. This report has reviewed various developmental and testing efforts with respect to flight path displays. Based on these findings, several conclusions and recommendations are enumerated.

Flight path displays provide pictorially presented command paths on a single CRT, which allow the pilot to visually perceive relative orientation, closure, and flight progress. Human factors research indicates the importance of aircraft orientation and motion perspective in helping the pilot successfully accomplish his flight tasks. The inclusion of a command flight path enhances the pilot's perspective view of his present and intended path of travel, plus relative deviation from the command path, better enabling him to make accurate control judgments. A flight path display which also includes a textural background and symbols providing earth-referenced information allows the pilot to view the scene as one which resembles the real world view outside his cockpit. A perspective view of lateral and vertical flight change is thus provided.

To emphasize the importance of visual perspective and orientation, one might imagine a situation where these dimensions were not provided. If a pilot were tasked to land on a non-textured surface, but his only visual aid was the view outside the cockpit, he would have extreme difficulty in judging vertical motion and distance from the surface, and he would be unable, if a horizon line were not immediately apparent, to judge pitch or roll attitude. No perspective view of his motion through space is provided, and the pilot would be unable to orient the aircraft properly. If, however, the pilot were able to make control judgments based on his ability to view a command pathway against a textured surface, one might see how much easier the pilot's task would be when a perspective view of the earth and relative deviation from a chosen course are provided.

Generally speaking, current display systems do not provide orientation, perspective, or closure rate cues. Pictorial flight path displays, however, are able to provide this kind of visual information. The formats of flight path displays reviewed in this paper have addressed the importance of these dimensions. The research comparing flight path and non-pathway displays provide statistical indications that aircraft orientation and motion perspective enable better pilot performance.

SECTION I
INTRODUCTION

Advances in the state-of-the-art of cathode ray tube (CRT) technology and microprocessor design, plus the increased flexibility of aircraft display symbology, have made possible and have encouraged research into the concept of the integrated flight path display, a format on which both the vertical and horizontal path appear. Developmental and experimental research involving flight path displays has been aimed toward creating a format which will facilitate the pilot's flight tasks by presenting on a single display[1] the vertical and horizontal situations of the aircraft with respect to a pictorially illustrated command flight path. This command path is drawn to resemble a highway or "pathway" which the pilot must follow either for navigation or to a touchdown on the runway. This report addresses the research and developmental efforts which have been made during the past two and a half decades with respect to flight path displays.

Currently used electro-mechanical attitude-director indicators and horizontal situation indicators are display systems which require a pilot to scan the displays for attitude, relative position, and numerical information regarding flight situation and to integrate these pieces of information into a mental image of his flight conditions or path. Flight path display formats differ in approach from these systems in that they provide a perspective drawing of a path the pilot must follow in order to accurately stay on course.

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[1] Baty's Coordinated Cockpit Display (see Section 2.1.1.7) is an exception to the one-CRT format; the display is a three-CRT configuration which provides command paths for three separate perspectives of aircraft flight.

Different authors have referred to flight path displays as path-in-the-sky, contact analog, three-dimensional, perspective, tunnel, channel, or pursuit displays. The various formats reflect a continuum of realism projected by pictorial displays, which Carel and Zilgalvis (1964) have categorized into three basic types: (1) literal (the symbols are drawn in real-world relationship and shape), (2) analog (accurate perspective pictures of a three-dimensional model and real-world dynamic response), and (3) skeletal (content is minimal and fragmented, but still is considered pictorial because there are geometric and motion similarities between the elements of the display and their real-world counterparts). The displays reviewed and discussed in this report vary along this visual reality continuum according to the degree of similarity between flight path display symbology and the real world. These variations account for the different terminology used to describe what will herein be referred to as flight path displays.

Research into the relative value of a flight path display as compared with other types of display systems has concerned itself with questions addressing decreased pilot training, reduction of pilot workload, accurate and flexible guidance and control during various flight maneuvers, improved aircraft weapon system performance, and safe and reliable landing capability.

The discussion which follows is a review of some of the technical and experimental research which has been done with respect to the flight path display concept. The parameters for each of the pathway displays discussed in this paper are enumerated and explained, and pilot performance during testing of the various displays is discussed. The geometry of display development plus pertinent human factors research with respect to pathway display formats are reviewed. Based on the findings of previous research, recommendations with respect to the development of future flight path displays are offered for consideration.

SECTION II

FLIGHT PATH DISPLAY DESCRIPTION

Several different types of flight path displays appear in the literature, and each differs from the others, to at least some degree, with respect to display symbology and format. The terminology applied to the various symbols also differs between displays, even when like or similar symbology appears. Also, when certain parametric information is displayed, it is indicated via different means in different displays, as for instance, a relative displacement in one display, versus a numerical readout in another. Labeled drawings of the displays and concise narratives describing the functions of the symbology which appears on each display are provided in Section 2.1. The terminology used to describe the displays will mirror that which was used by the authors of the referenced reports so as to maintain as closely as possible the correct interpretation and intent.

2.1 Symbol Dynamics

A total of ten flight path displays were reviewed and selected for inclusion in this report. They have been categorized under two separate types of displays--those designed for use in fixed wing aircraft, and those designed for use in rotary wing aircraft.

2.1.1 Fixed Wing Aircraft Displays

Seven of these ten flight path displays were intended for use in fixed wing aircraft. Their descriptions appear below.

2.1.1.1 Path-in-the-Sky Display; Knox and Leavitt

Knox and Leavitt (1977) developed a contact analog display, which they called Path-in-the-Sky (PITS), designed to integrate information pertaining to airplane attitude, airplane kinematic performance, navigation situation and path prediction onto one CRT display (see Fig. 1).

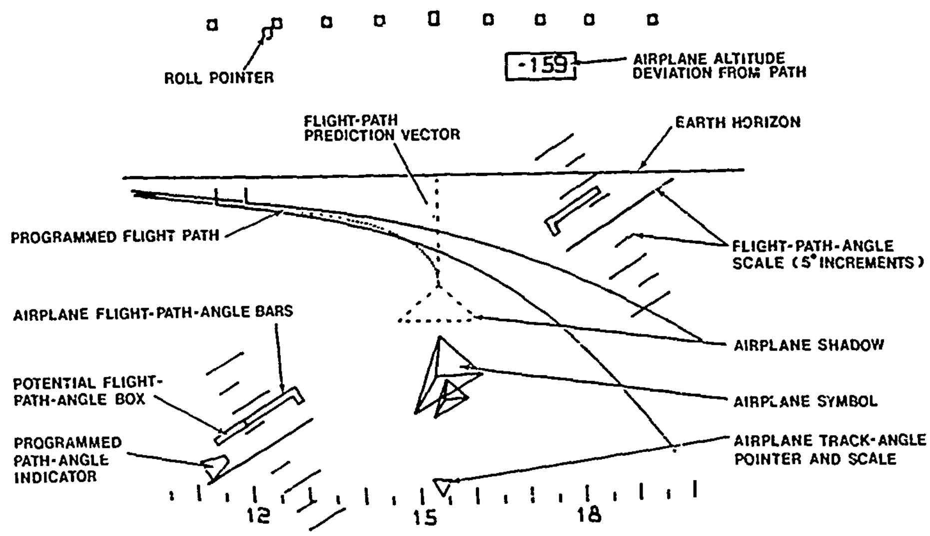

Figure 1. Path-in-the-Sky Display (From "Description of Path-in-the-Sky Contact Analog Piloting Display", Charles E. Knox and John Leavitt, NASA Technical Memorandum 74057, October 1977).

The symbols displaying path-tracking situation information are an airplane symbol, a vertical projection ("shadow") of the airplane symbol with an extended center line drawn at the altitude of the path, a flight-path predictor, and a drawing of the programmed path. These are drawn in a perspective display format as if the observer's eye were located above and behind the airplane. The airplane symbol (a tetrahedron plus a smaller tetrahedron at the tail) visually indicates pitch changes; the symbol rolls and pitches about its apex (the aircraft's true position with respect to the path) in accord with the real airplane's attitude. The vertical projection of the airplane symbol, which indicates altitude deviation and always remains in vertical alignment with the airplane symbol, is displaced above the airplane symbol when the airplane is flying below the programmed path, and is displaced below it when the airplane is flying above the programmed path. Left and right lateral tracking deviations are indicated by left or right (respectively) displacements of the airplane symbol and shadow from the path. Altitude deviations from the programmed path are shown in numerical form in a box in the upper right corner of the display. A dashed line flight path predictor vector in the horizontal plane is attached to the shadow and indicates the airplane's predicted path for the next ten seconds of flight at the aircraft's present bank angle and ground speed. An extended shadow center line drawn from the apex of the shadow in the direction of the present track angle is shown to aid the pilot with the lateral tracking task. The programmed path is drawn in perspective (behind and above the real airplane). It disappears from the display at the fixed horizon line when it is not within the horizontal and vertical field of view. A set of vertical poles, one on each side of the path, is drawn at points of transition between curved and straight segments. Programmed path altitude changes are drawn with a straight line between waypoints. A flight path angle scale, appearing on both the left and right sides of the display, and graduated in 5° increments with a range of $\pm 20^{\circ}$, is fixed vertically, but rotates with the airplane symbol about its apex during banking maneuvers. Twin L-shaped bars move vertically on the scale to provide an Earth-referenced airplane flight path angle. These bars rotate with the scale when the airplane is banked. A potential flight path angle box (left side of display) indicates acceleration in the direction of the airplane's flight path. The box is drawn relative to the bars as a form of thrust and energy management indicators. A pilot knows that he will maintain his present ground speed if the bars and box are adjacent. If the box were below the bars, the aircraft would be slowing down; if it were above the bars, the aircraft would be speeding up. The vertical angle of the programmed path is illustrated with a truncated triangle, called a programmed path angle indicator. The indicator moves vertically along the scale, pointing to the programmed path. An airplane track angle scale moves left or right as the track of the aircraft changes; a small triangle fixed to the center of this scale points to the present track of the aircraft. A roll scale (wings level, 10°, 20°, 30°, and 45° tic marks) appears at the top of the display, and a pointer moves under the scale in the direction of the bank angle. The roll pointer rolls with the airplane symbol and flight path angle scale during banking maneuvers.

A pilot and his aircraft are tracking correctly when flying down the center of the programmed path with the airplane symbol super-imposed over the shadow. The flight path angle bars should ideally be parallel with the programmed path angle indicator. The pilot must make adjustments in these parameters as the programmed path changes direction vertically or laterally.

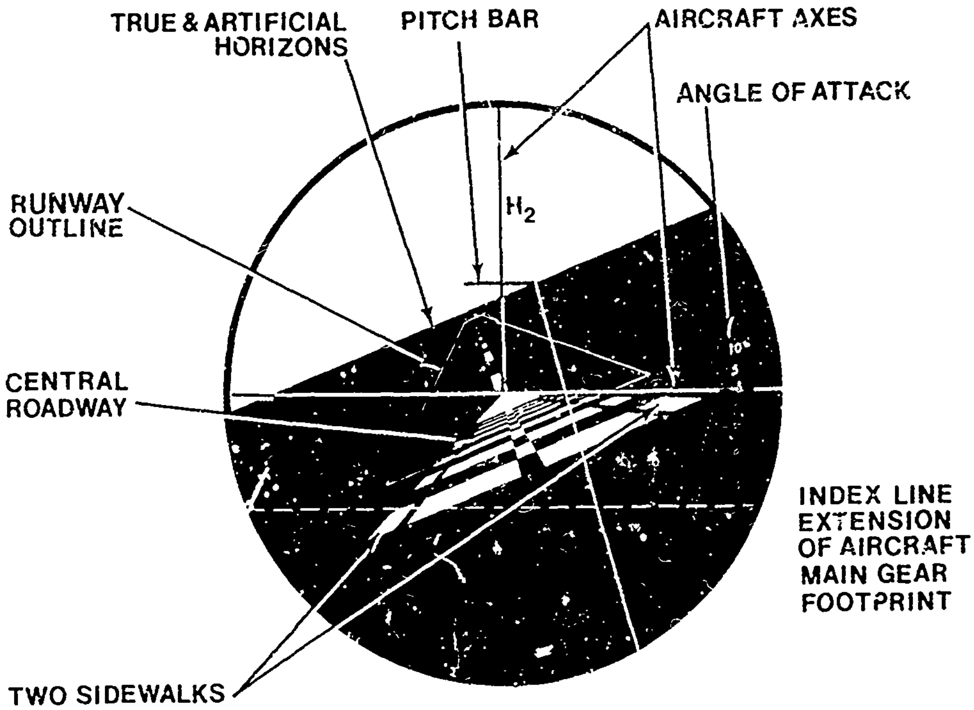

Figure 2. Farrand Path-in-the-Sky head-Up Display (from "A Multi-Purpose Wide Field, Three Dimensional Head-Up Display for Aircraft", Joseph A. LaRussa, Farrand Optical Co., Inc., Valhalla NY, circa 1960).

2.1.1.2 Farrand Path-in-the-Sky Head-Up Display; LaRussa

LaRussa (circa 1960) reported on the development of the Farrand Path-in-the-Sky Head-Up display, which provides a true three-dimensional roadway in the sky projected through the windscreen and superimposed on the real world. The path can be made to extend from the aircraft to any desired location. Additionally, actual airspeed, desired airspeed, steering errors, crab angle, roll attitude, angle of attack, runway outline and an artificial horizon are provided as picture analogs.

In the Farrand display, the artificial horizon, aircraft axes, a central roadway and two sidewalks on either side of the roadway combine to create an inside-out perspective of the flight conditions. The index line which appears in the lower half of the display depicts an extension of the aircraft main gear footprint along the aircraft velocity vector to a point forward of the aircraft where the roadway should first become visible to the pilot.

The pilot's task is to "guide" his aircraft down the command path, maintaining command pitch angle and level flight by utilizing the pitch bar and aircraft axes as vertical and horizontal references with which to align the horizon line and roadway centerline. As the aircraft flies over the road, the pattern in the road appears to roll under the aircraft at actual speed. The sidewalks, depending on whether they move at a slower or faster rate than the central pathway, provide cues for increasing or decreasing velocity.

Where no ILS exists, the system with an inertial platform may be used to generate a glideslope. The pilot flies parallel to the ground plane and sets a desired glideslope. The glideslope intersects the ground in advance of the runway while the pilot lines up with the runway centerline, the aircraft reaches the glideslope and the Path-in-the-Sky intersects the runway at a desired touchdown point. The pilot then freezes the display so that it becomes inertially stable; he then proceeds to fly the aircraft down the pathway to a landing.

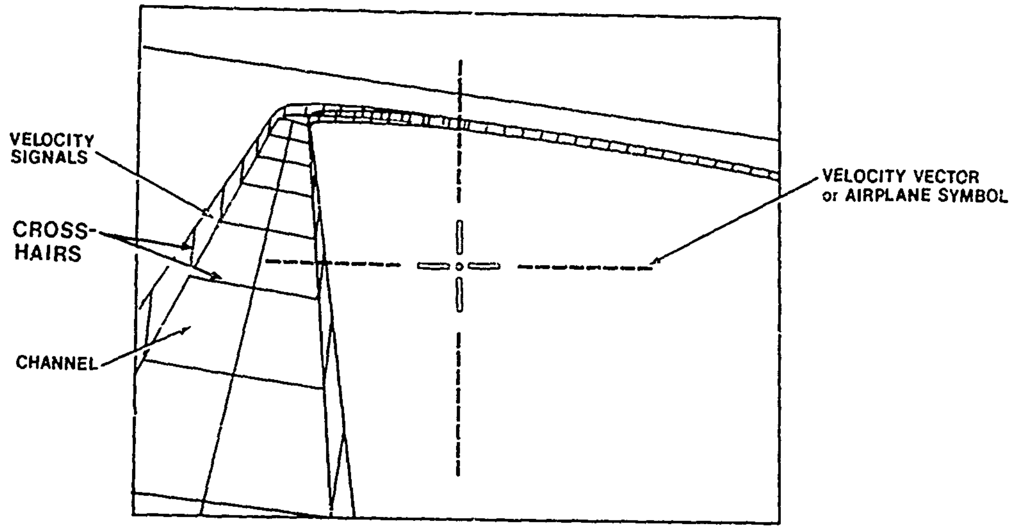

Figure 3. Channel Display (from "On a Solution of the Residual Problems of Aircraft Control Especially in Zero Visibility Landings by the Pictorially Quantitative and True Perspective Channel Display", V. Wilckens, Berlin, Germany, 1973).

2.1.1.3 Channel Display; Wilckens

Wilckens (1973) proposed a true perspective, contact-analogous and "inside-out" display system, which includes (1) velocity information and (2) path-guidance information (showing lateral and vertical position information). This format illustrates nominal velocity relative to the nominal velocity of a moving reference system. A "flow" of cross hair images to the center indicates reduced velocity, and vice versa. The display, the author advocated, could be interpreted as command for acceleration or deceleration.

Path guidance information appears in the form of a curved channel or "street" which, in contrast to the velocity signals, incorporates space-fixed structural elements. Attitude angle appears the same as for visual contact. Wilckens advocated highly sensitive lateral and vertical position information to be incorporated into the channel display. The pilot's tasks require him to guide the aircraft down the middle of the channel, with the velocity vector aligned in its center. If his speed is accurate, the velocity signals will appear stable.

2.1.1.4 Three Dimensional Channel Display; Kraiss and Schubert

Kraiss and Schubert (1976) evaluated (see Section 3.1.1) a rectangular, three-dimensional command path they called a channel. Their channel display (see Fig. 4) is similar to Wilckens'. Six rectangularly arranged reference points may be used for qualitative readings of pitch and heading angles and for the quantitative estimation of horizontal and lateral deviations. Three additional points in the lower part of the display are roll angle references. The actual track predictor is a dashed line which bends laterally with respect to bank angles and a V-shaped symbol that corresponds to the far end of the channel. The dashed center lines and the stripes on the outside of the channel move toward the pilot, giving an impression about the aircraft's actual speed. If a pilot is flying correctly on the programmed path, the V-sign will be aligned to the far channel end, thereby allowing the dashed centerline and dashed predictor line to fall together. The command channel will fit exactly between the four reference points.

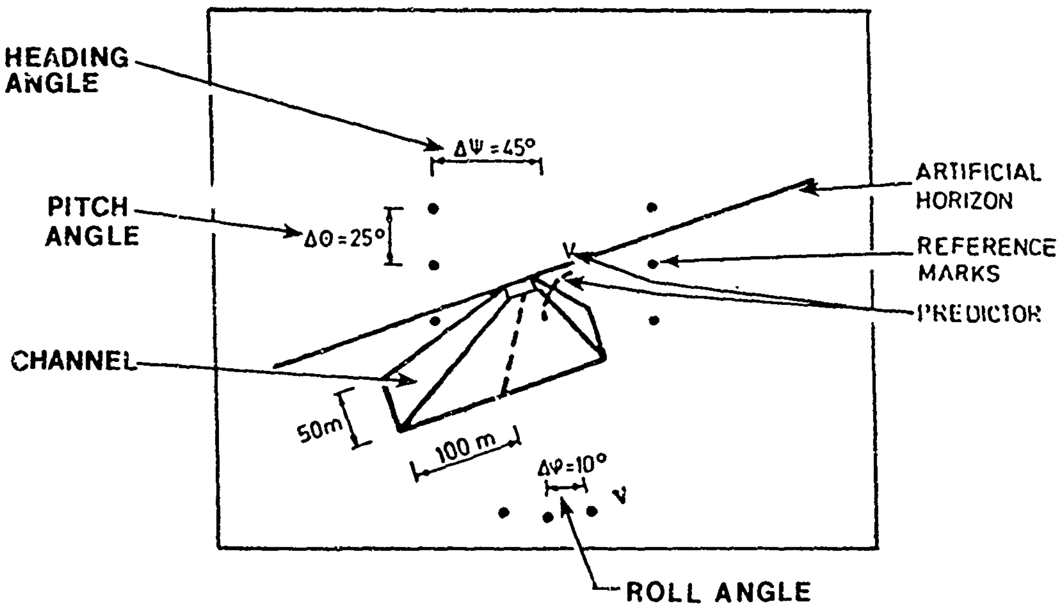

Figure 4. Three Dimensional Channel Display (from "Comparative Experimental Evaluation of Two-Dimensional and Pseudo-Perspective Displays for Guidance and Control", K.F. Krauss and E. Schubert, Research Institute for Human Engineering, Buschstrausee, Germany, November 1976).

2.1.1.5 Glideslope/Localizer Path Display; Eisele, Willeges, and Roscoe

Eisele, Willeges, and Roscoe (1976) tested (see Section 3.1.2) various combinations of like symbology in a pursuit display format designed for landing modes. The displays differ in that each one tested was some combination of the following symbology. The complete display, as proposed by Eisele, et. al., involves a perspective glidepath analogous to a "highway in the sky". The glidepath is created symbolically with glideslope/localizer T-bars which the pilot is to follow by aligning his aircraft laterally and vertically so that the crests of the T-bars align parallel to the horizon line, and aim toward the touchdown aimpoint. The attitude index lines indicate a range within which the horizon line must fall for accurate pitch; this index also aids the pilot in controlling bank attitude in the same manner. A velocity vector in the form of horizontal lines appears, indicating the relative speed with which an aircraft is moving (although the authors do not describe how they function). Flight path predictors, short vertical lines which intersect the lines of the velocity vector, indicate the present and future flight path which the pilot uses as an indicator of proximity to the command path for purposes of capturing the path. The T-bars are aligned so that a pilot may judge his distance from the runway aimpoint, and command path perspectively. In the tested displays, a grid plane appears which the pilot may use to approximate the range to aimpoint, provided that the squares of the grid represent a given distance. The authors defined the resulting flight control task as one of pursuit rather than compensation, a pursuit display having at least two moving indices with a common reference system, one representing the pilot's own airplane or projected flight path plus one representing his desired position or flight path.

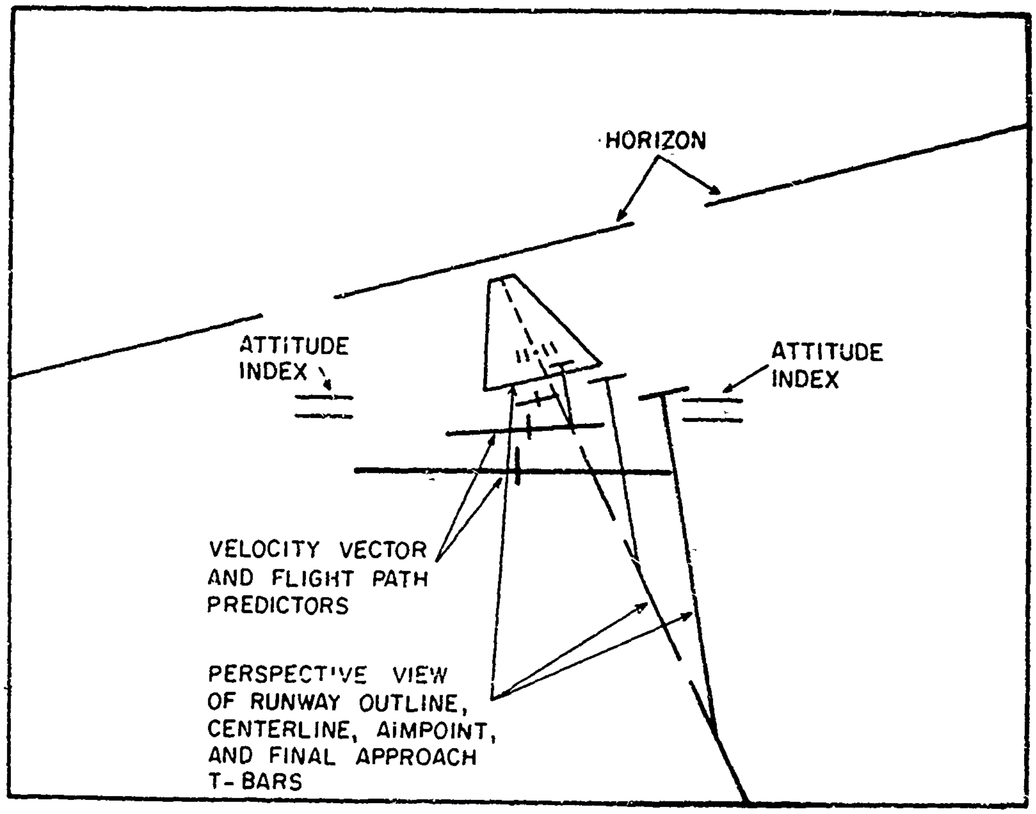

Figure 5. Glideslope/Localizer Path Display (from "The Isolation of Minimum Sets of Visual Image Cues Sufficient for Spatial Orientation During Aircraft Landing Approaches", J.E. Eisele, R.C. Willeges, S.N. Roscoe, Aviation Research Laboratory, University of Illinois at Urbana-Champaign, Savoy IL, November 1976).

2.1.1.6 Digital Contact Analog Display; Wild

Wild (1966) described the General Electric Contact Analog Display, prepared for Joint Army-Navy Aircraft Instrumentation Research (JANAIR), as an advanced laboratory version of a digitally implemented contact analog display system. The display features (see Fig. 6) a textured ground plane and sky plane, terrain information, an airborne target symbol, a weapons symbol, an impact point (or velocity vector) symbol, velocity cursor, two sets of programmer-selectable 4-digit numbers, and an earth-stabilized flight path which could be used as a flight director.

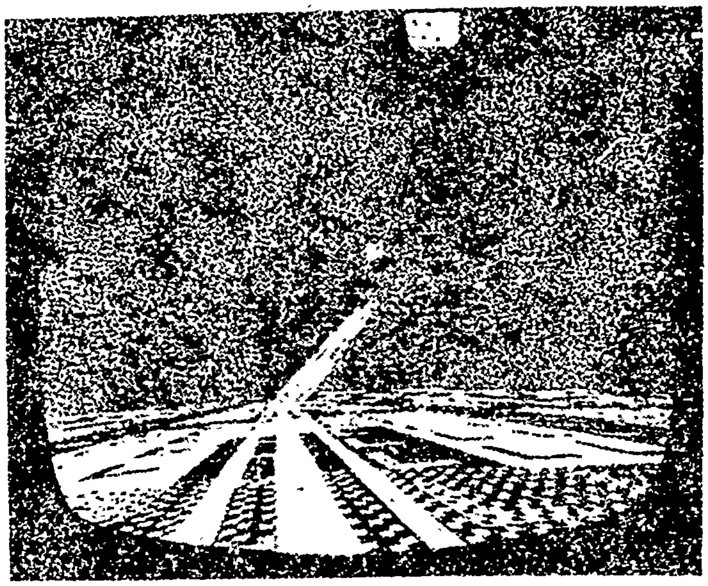

Figure 6. Digital Contact Analog Display (from "Advanced Digital Contact Analog Research", E.C. Wild, General Electric Company, Electronics Laboratory, Syracuse NY, June 1966).

The pilot's general task is to assess his flight conditions perspectively in relationship to the various symbols. For piloting/referential purposes, the ground plane is tangent to the earth's surface at the nadir of the airplane. The display system was designed for use with manned aircraft and weapon system simulators. The pilot's task involving weapons and target requires him to position the weapon symbol, or hollow square (which represents the aircraft's weapon, and appears directly above the impact point of the aircraft) so that it superimposes over the airborne target symbol (a solid square which changes in size according to the aircraft's range to the target). The display provides a velocity cursor (a line stretching horizontally across the screen), which moves vertically to indicate speed. (The author is not explicit as to how movement indicates speed.)

A runway and two obstacles appear on the ground texture perspectively, and these, combined with the changing texture of the ground and runway as altitude and attitude vary, give the pilot a perspective view of his flight situation.

The flight path, which is earth-referenced, is capable of commanding all six degrees of motion and thus indicates pitch, roll and yaw attitudes, plus altitude, lateral displacement and heading (ground plane heading and horizon may be trimmed, i.e., pattern can be oriented in selected direction and altitude).

2.1.1.7 Coordinated Cockpit Display; Baty

Baty (1976) proposed a pathway display which deviates somewhat from other flight path displays in that the format is comprised of three separate components, arranged as illustrated below (see Fig. 7). It is included in this report, however, because it provides command path information for each of the three axes, and thus provides an alternative to the presently popular idea of flight path display formats. It is included, also, for another reason: the cross-check capability (each of the three displays shares one of its two dimensions with one of the other two displays) helps satisfy the pilot's need for accuracy verification.

The three-display configuration is based on three orthogonal planes of the aircraft situation: (1) perpendicular to the pilot's forward line-of-sight, (2) parallel to the ground, and (3) perpendicular to the other two. These are interpreted for the pilot through a vertical situation display, a horizontal situation display, and a side vertical situation display, respectively. The displays are designed in order to relate qualitative information to quantitative information. The author proposed a color-coding scheme that is identical across all three displays which, briefly, would be assigned as follows: red for control information, green for performance information, and yellow for navigation information.

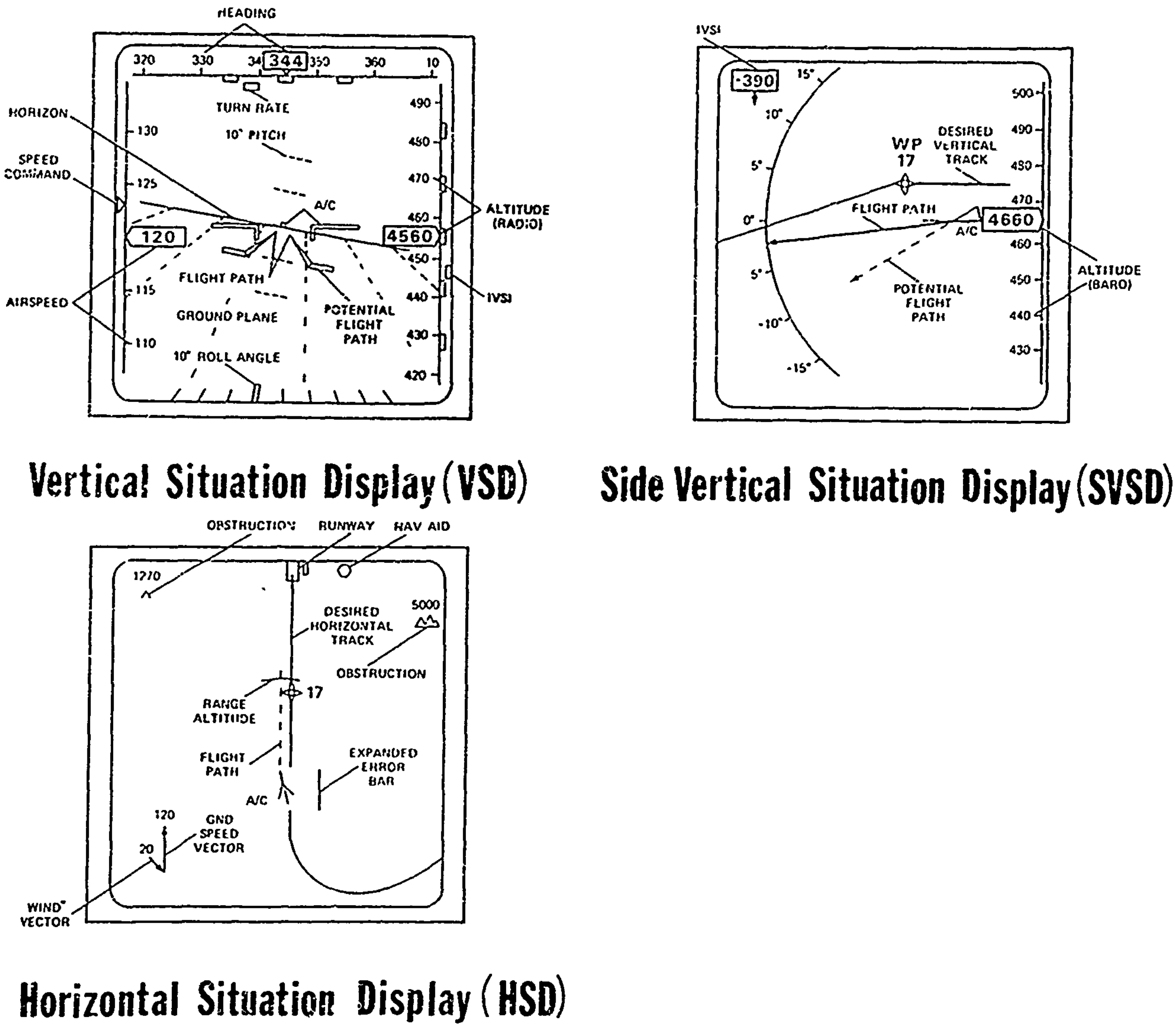

Figure 7. Coordinated Cockpit Display (from "Rationale and Description of a Coordinated Cockpit Display for Aircraft Flight Management", D.L. Baty, NASA Technical Memorandum X-3457, Ames Research Center, Moffett Field CA, November 1976).

The Vertical Situation Display (VSD) is the primary display for aircraft attitude. The fixed aircraft symbol (L-bars plus a velocity vector) when compared with the horizon line's lateral displacement and roll angle marker (across the bottom of the display) indicates bank; when compared with vertical displacement from the zero-degree pitch marker, pitch angle is indicated. A perspective dot pattern appears on the ground plane, serving to (1) differentiate between ground and sky, and

(2) indicate speed via the streaming effect of the passing ground. Heading, altitude and airspeed are read by a combination moving tape and digital readout. Turn rate (rate of change of heading) and instantaneous vertical speed indication, or IVSI (rate of change of altitude), are indicated with markers along the heading and altitude scales, respectively.

Flight path angle (FPA) and potential flight path angle (PFPA) are indicated with one symbol, to be used in relationship to the velocity vector, or aiming point. The FPA/PFPA symbol is used to show flight path angle relative to the horizon or to any spatially located point such as a three dimensional waypoint, runway threshold, or another aircraft. The symbol functions in the following way: when the PFPA is level with the FPA, speed is constant. If PFPA is above FPA, acceleration is positive, so speed will increase. If PFPA is below FPA, the acceleration is negative and speed will decrease. A pilot may change pitch attitude to maintain current airspeed without changing thrust, or, he may change throttle until the PFPA reads the same value as for flight path.

The Side Vertical Situation Display (SVSD) is designed to relate present aircraft altitude to future altitude requirements. The aircraft symbol remains fixed at the altitude digital readout box. The moving tape/digital readout operates the same as in the VSD, except that in the SVSD, altitude is barometric, and in the VSD it is from radio. Significant terrain features (not pictured) increase pilot awareness of terrain altitude. Flight path angle and potential flight path angle are read against an expanded angle scale. The aircraft symbol rotates about its midpoint to indicate pitch attitude. The IVSI readout (negative or positive) in the upper left corner of the display shows absolute vertical speed, which supplements the analogue readout on the VSD. The arrow appearing above or below the box reinforces the sign information of the up or down velocity of the aircraft. The desired vertical track is a segmented line moving toward the aircraft symbol, and relevant tags indicate waypoints, marker beacons, and so forth.

The Horizontal Situation Display (HSD) appears as though the pilot is looking at a map -- it represents the aircraft's geographic position -- relative to a desired track (as pictured), navigation aids, waypoints, runways, or prominent geographic features. The lateral track error may be displayed with a portion of the desired track displaced to the right or left to indicate the direction in which the pilot must fly in order to correctly resume his course position. A range altitude indicator appears on the display to show the point at which the next waypoint altitude will be reached if present vertical situation is maintained. Ground speed and wind speed vectors appear together in the lower left corner, providing the pilot with an additional means of checking and assessing his flight conditions.

It is the pilot's task to assess the information he needs from scanning displays and to note any critical changes in his flight conditions as indicated by any display(s) he currently is watching. He must correct navigational errors by first selecting the display which can help him most at a particular instance, and checking his correction by re-scanning all the displays.

2.1.2 Rotary Wing Aircraft Displays

The remaining three flight path displays included for discussion in this report were designed for use in rotary wing aircraft, and are described below.

2.1.2.1 SAAB Perspective Display; Murphy, McGee, Palmer, Paulk and Wempe

Pilot performance was investigated (see Section 3.2.1) using a modified SAAB perspective display. The SAAB display (see Fig. 8) indicates altitude error using the upper ends of perspective "poles" in relationship to the moving horizon line. Flight path angle and course are indicated by use of a velocity vector and an aiming dot in a "fly-from" orientation. Altitude error and bank information are pre-

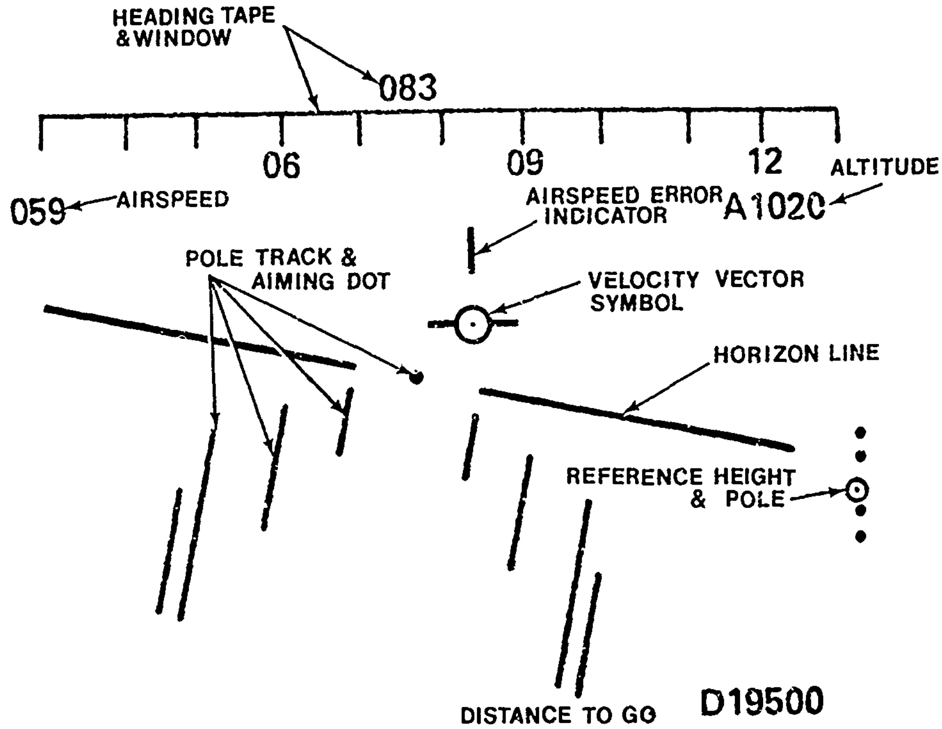

Figure 8. SAAB Perspective Display (from "Simulator Evaluation of Three Situation and Guidance Displays for V/STOL Zero-Zero Landings", M.R. Murphy, L.A. McGee, E.A. Palmer, C.H. Paulk and T.E. Wempe, NASA Ames Research Center, Moffett Field CA, April 1974).

sented in conventional "fly-to" orientations. A reference height pole is provided for determining absolute altitude. The distance of the airspeed error indicator from the periphery of the velocity vector symbol indicates airspeed error. Altitude rate is indicated which is similar to a glide-slope indicator. Digital readouts for altitude, airspeed, and distance to go appear on the display. A heading tape and window indicate heading. In the SAAB display, the pilot's task is to align the pole track and aiming dot with the velocity vector symbol.

2.1.2.2 Pathway Display and Pathway with Tarstrips Display; Sgro and Dougherty

Sgro and Dougherty[1] (1963) developed and evaluated (see Section 3.2.2) two types of pathway displays for helicopter flight maneuvers (which, by nature, differ from airplane flight maneuvers).

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[1]Emery and Dougherty used these same displays in their evaluations (see Section 3.2.2).

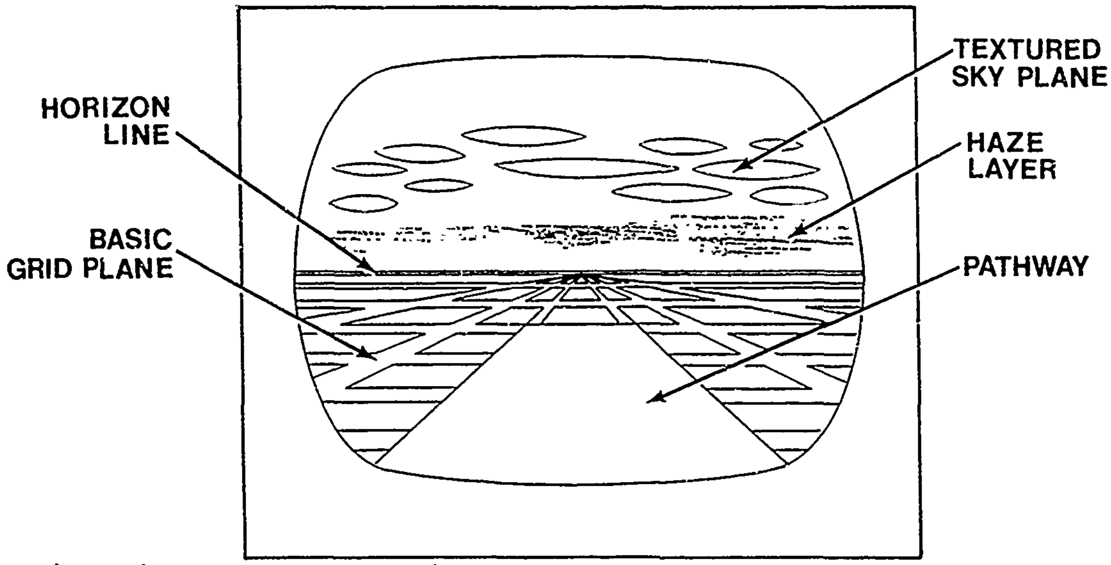


Figure 9. Pathway Display (from "Contact Analog Simulator Evaluations: Hovering and Air Taxi Maneuvers", J.A. Sgro and D.J. Dougherty, Bell Helicopter Co., Report No. D228-421-016, Fort Worth TX, December 1963).

The first display showed a basic grid plane which moves perspectively with the movement of the aircraft, relating lateral and vertical flight deviations to the pilot. The grid (white lines on a black background, not shown in illustration) is presented with real world perspective (a 360° turn presentation capability) with four vanishing points termed cardinal heading. The squares decrease in size as the aircraft increases its altitude. Each square represents twelve feet per side. Every eighth line is wider than the others to assist in altitude reading. A sky texture is shown above a fixed accentuated horizon line. A simulated haze layer (5° viewing angle) appears just below the horizon line to prevent confusion during convergence of grid lines forming linear perspective. The earth stabilized command pathway represents a 30-foot wide area over the grid plane. The pathway lies across the grid line during lateral deviations and the pathway remains fixed in size, appearing to move with the pilot during vertical deviations. The second pathway display includes tarstrips (or cross bars situated 30 feet apart) which move toward the observer indicating ground speed information. Correctly

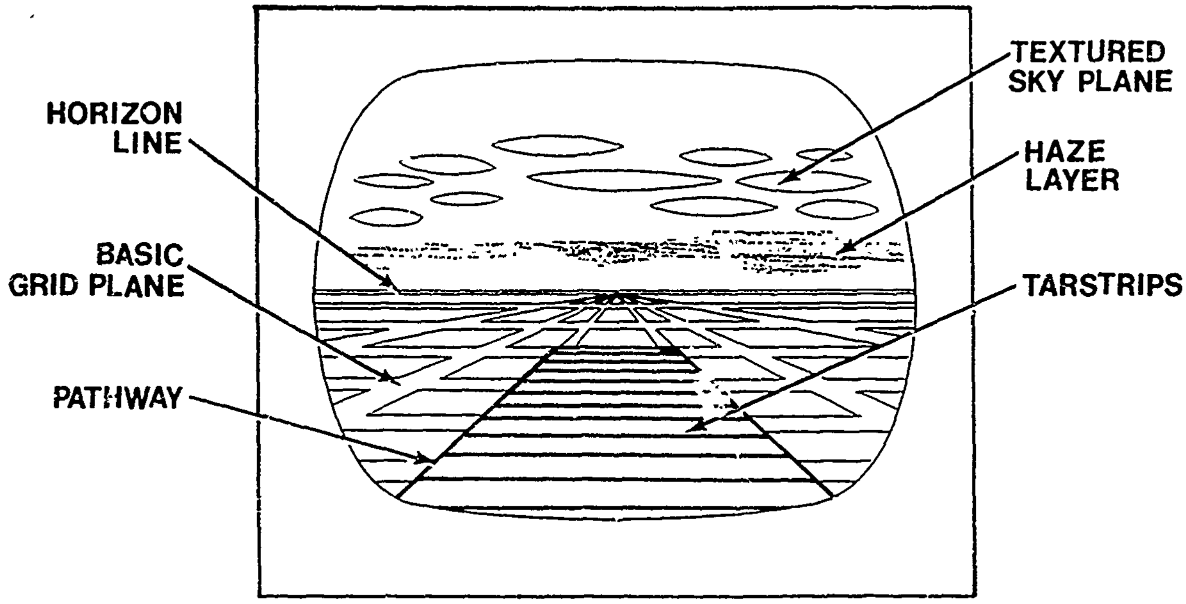


Figure 10. Pathway with Tarstrips Display (From "Contact Analog Simulator Evaluations: Hovering and Air Taxi Maneuvers", J.A. Sgro and D.J. Dougherty, Bell Helicopter Co., Report No. D228-421-016, Fort Worth TX, December 1963).

flying the aircraft with the Sgro/Dougherty display requires a pilot to maneuver the aircraft so that the grid appears to be moving straight toward the pilot to prevent and/or correct for the grid lines slanting diagonally. Also, he must manipulate the aircraft vertically such that the end of the pathway does not appear stationary or fixed in size.

2.1.2.3 Contact Analog Display; Curtin, Emery, Elam and Dougherty

Curtin, Emery, Elam, and Dougherty (1966) developed for the JANAIR Program a vertical display, or contact analog, used during flight tests (see Section 3.2.4) in a Bell UH-1 helicopter. The display was tested using different combinations of available symbology, which included a ground plane, a flight pathway with tarstrips and speed command marker, a ground position identifier (GPI) positioned independently on the ground plane, sky texture (clouds), and director symbols in the form of a cross and square. The basic format for the display (see Fig. 11) appears on the following page. The display with the pathway would appear similar to the display in Figure 10.

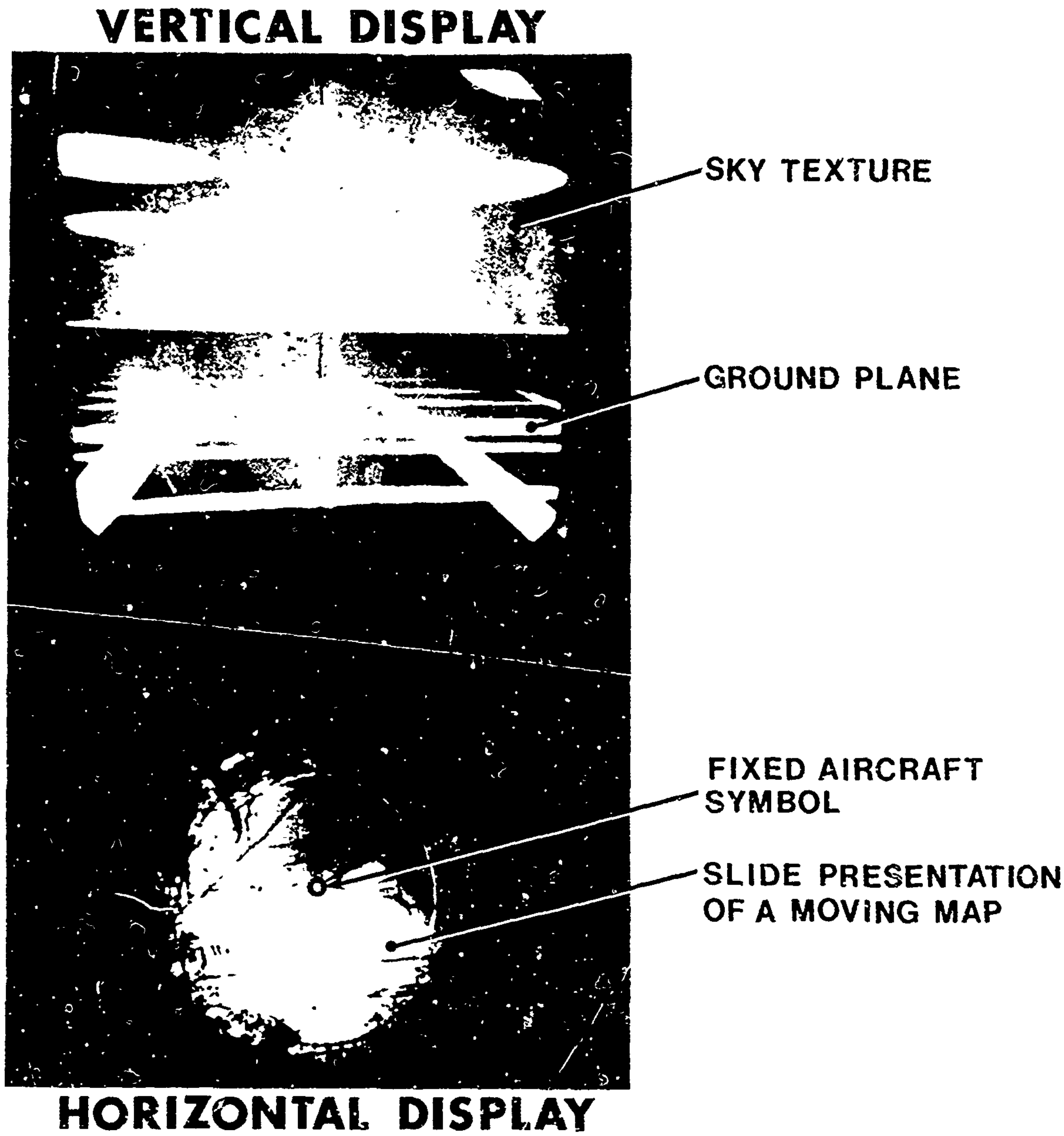


Figure 11. Contact Analog Display (from "Flight Evaluation of the Contact Analog Pictorial Display System", J.G. Curtin, J.H. Emery, C.B. Elam and D.J. Dougherty, Bell Helicopter Co., Fort Worth TX, February 1966).

The ground texture, GPI, and pathway have six degrees of freedom. The cloud texture moves only in response to pitch, roll and yaw and supplies only orientation information during extreme attitudes when the horizon line or ground texture become obscured. The horizontal display (a slide presentation of a moving map with a fixed aircraft symbol in the center of the display) appears directly below the vertical display and provides heading information.

2.1.3 Summary

An analysis of the referenced flight path displays shows that several levels of display integration have been addressed by the various formats. Each has been described separately in terms of its design and intended usage. When judging the displays in terms of their effectiveness, it must be remembered that required of every display are pitch, attitude and roll indicators in order that the pilot may accurately and safely maneuver the aircraft. Tables 1 and 2 summarize the flight path displays discussed in Sections 2.1.1 and 2.1.2, and analyze them with respect to the following categories:

1) command
2) control
3) performance
4) navigation

These four categories of information are found on contemporary instrument panels and are basic to the principles of attitude instrument flight as currently taught in the USAF. They are defined in Air Force Manual 51-37, Flying Training, Instrument Flying, as follows:

1) command: steering displays combining attitude, heading and target or course signals to form integrated attitude commands to intercept and maintain a desired path;

Table 1

COMMAND, CONTROL, PERFORMANCE AND NAVIGATION DIMENSIONS OF FLIGHT PATH DISPLAYS

Fixed Wing Aircraft Displays

Flight Path Displays	COMMAND	CONTROL	PERFORMANCE	NAVIGATION
MECHANICAL OR ELECTRONIC ATTITUDE DIRECTOR INDICATOR/HORIZONTAL SITUATION INDICATOR	Pitch steering bar Bank steering bar	Attitude indicator Power indicator	Airspeed Altitude Heading Vertical velocity Angle of attack	Bearing pointer(s) Course deviation indicator Glideslope deviation indicator Distance measuring equipment
Knox and Leavitt: PATH-IN-THE-SKY DISPLAY		Bank angle Pitch changes Airplane symbol	Flight path angle Flight path acceleration Altitude deviation Heading	Vertical projection of airplane symbol with extended line drawn at altitude of path Flight path predicator Programmed path Vertical path deviation Lateral path deviation
LaRussa: FARRAND PATH-IN-THE-SKY HEAD UP DISPLAY	Pitch bar Aircraft axes Steering errors	Roll attitude Pitch attitude	Desired airspeed Airspeed Angle of attack Velocity vector	Crab angle Runway outline Pathway (central roadway plus two sidewalks) Index line
Wilckens: CHANNEL DISPLAY	(Acceleration/deceleration command)[1]	Attitude	Velocity	Path guidance Lateral position information Vertical position information Glide angle Trajectory vector
Kraiss and Schubert: THREE DIMENSIONAL CHANNEL DISPLAY		Pitch angle Roll angle	Heading angle Speed indicator	Command path Lateral deviation Horizontal deviation Actual track predictor
Eisele, Willeges and Roscoe: GLIDESLOPE/LOCALIZER PATH DISPLAY		Pitch index Bank attitude(approx)	Velocity vector Flight path Flight path predictor	Touchdown aimpoint Vertical deviation Lateral deviation Glideslope-localizer T-bars Range to aimpoint Texture grid Desired final approach path Perspective view of runway
Wild: DIGITAL CONTACT ANALOG DISPLAY	Climb Left and right turn Weapons symbol	Roll attitude Pitch attitude	Heading Altitude Velocity vector (or impact point) Two 4-digit numbers	Runway Obstacles Runway texture Ground texture Target
Baty: COORDINATED COCKPIT DISPLAY Vertical Situation Display		Pitch angle Bank angle Potential flight path Aircraft symbol	Heading Altitude (radio) Airspeed Turn rate Instantaneous vertical speed indicator (IVSI) Flight path angle	Aircraft symbol Horizon line Moving perspective Ground plane
COORDINATED COCKPIT DISPLAY Horizontal Situation Display		Aircraft symbol	Flight path Range altitude Groundspeed Windspeed	Desired course line Navigation aids Waypoints Runways Obstructions Lateral track error
COORDINATED COCKPIT DISPLAY Side Vertical Situation Display		Aircraft symbol Potential flight path angle	Altitude (barometric) Flight path angle IVSI	Terrain features Desired vertical track Waypoints, beacons, etc.

[1] Possible interpretation according to Wilckens

Table 2

COMMAND, CONTROL, PERFORMANCE AND NAVIGATION DIMENSIONS OF FLIGHT PATH DISPLAYS

Rotary Wing Aircraft Displays

Flight Path Displays	COMMAND	CONTROL	PERFORMANCE	NAVIGATION
Murphy, McGee, Palmer, Paulk and Wempe: SAAB PERSPECTIVE DISPLAY (MODIFIED)		Flight path angle Roll angle	Flight path angle error Altitude Heading Airspeed Altitude rate Airspeed error	Vertical deviation Lateral deviation Course error Distance-To-Go
Sgro and Dougherty[1] (JANAIR): PATHWAY DISPLAY			Altitude Heading	Command pathway Basic grid plane Lateral deviation Vertical deviation
Sgro and Dougherty[2] (JANAIR): PATHWAY WITH TARSTRIPS DISPLAY			Altitude Heading Speed indication (tarstrips on pathway)	Command pathway Basic grid plane Lateral deviation Vertical deviation
Curtin, Emery, Elam, Dougherty: CONTACT ANALOG DISPLAY WITH PATHWAY.			Altitude error Speed error Bearing to destination Distance to destination N to destination E to destination	Tarstrip speed Path bearing Path scope Lateral deviation Distance to touchdown

[1,2] Emery and Dougherty used these same displays in their evaluations (See Section 3.2.3)

2) control: instruments displaying attitude and power indications and calibrated to permit attitude and power adjustments in definite amounts, (i.e. thrust or drag relationship);

3) performance: instruments indicating the aircraft's actual performance; and

4) navigation: instruments which indicate the position of the aircraft in relation to a selected navigation facility or fix.

Tables 1 and 2 are intended to facilitate comparisons between displays. The terminology used to describe the displays will be that which was used in the referenced documents. For reference purposes only, Table 1 will include an analysis of mechanical/electronic attitude director indicators and horizontal situation indicators like those found in current aircraft. Illustrations of an ADI/HSI and an EADI are provided in Appendix B of this report to aid in comparing current and flight path displays.

2.2 FORMAT DESIGN

The following information addresses the actual development -- geometric design and symbology content -- of flight path displays. Included in this section are remarks by the scientists/engineers who developed the displays (discussed in the previous subsection) as to the various methods they used to format and build their displays.

2.2.1 Field of View

No concensus has been achieved on field-of-view for flight path displays. Various authors (as noted below) recommended fields-of-view from 12.5° to 180° and angles in-between.

Knox and Leavitt (1977) reported that a 60° field-of-view (FOV) with a corresponding 45° effective field of view (or actual angle between the top and bottom of the viewing screen) resulted in good definition of vertical and lateral path deviations (see Fig. 1). They advocated that FOV should be selected before other geometric parameters, so that it equals twice the angle between the horizon line on the viewing screen and either the top or bottom of the viewing screen, whichever is larger. If the horizon line is drawn other than at the vertical center of the viewing screen, a portion of the display will be clipped off, resulting in a smaller actual FOV. Increasing the FOV moves the eye position closer to the screen, creating two effects on the display's perspectives: (a) increase in size of path, and (b) eye position adjustment, whereas the pilot looks more on top of the aircraft symbol and path, but less toward the rear of the airplane symbol.

Wilckens (1973) advocated a viewing angle (see Fig. 3) of up to 180° (if necessary). As steering progresses, the angle may be reduced to a value more favorable for precise steering.

Display viewing angle may, Wild (1966) reported, be set to any angle between $\pm 63.4^{\circ}$ and $\pm 12.5^{\circ}$ (see Fig. 6).

Sgro and Dougherty (1963) employed a 12-by-12-inch image and a 30° X 30° field-of-view (see Fig. 9).

Carel and Zilgalvis (1964) reported, based on a series of studies, that in literal displays, increasing hazard exists when departing from an image magnification factor of 1.2. In general, they stated, it is more important for the pilot to see where he is going than where the aircraft is pointed. Thus, they suggest that the size of a literal display should be calculated from the relationship $S = d \tan (a_L + 3^{\circ})$ where $S = 1/2$ display height, d = viewing distance, a_L = maximum angle of attack during landing, and 3° = constant to assure visibility of this amount around the velocity vector, assuming that the horizon null appears at the center of the display when pitch equals 0^{o} and that unit magnification is used. (Author's note: according to Air Force mil specs, a 28-inch viewing distance and a 13^{o} maximum angle of attack are required for fighter aircraft displays. These figures, when substituted in the referenced formula, reveal that a display whose vertical dimension is @ 16 inches (28 x .28675 x 2 = 16.058) would be necessary to satisfy the requirements set forth by Carel and Zilgalvis for a literal display. However, implied in this finding is that a literal display would not, due to its large size, be feasible in a fighter cockpit).

Emery and Dougherty (1965) evaluated different display conditions with respect to screen size and image field-of-view. Both six-inch square and twelve-inch square screens were tested at viewing distances which yielded visual angles of fifteen degrees and thirty degrees. Thirty-degree and sixty-degree image fields-of-view were tested with the two screen sizes. Their findings revealed that image field-of-view did not affect pilot performance measures; approach airspeed control was significantly better ($p < .05$) when the pilots used the twelve-inch by twelve-inch screen (since, the authors surmised, the pitch controlling factor was more easily discernible on the larger screen), but final touchdown position control was better ($p < .05$) when pilots used the six-inch by six-inch screen (attributable to their contention that television raster scan on the 6 inch screen resulted in better visual resolution of information on the display than on the 12 inch screen).

2.2.2 Relative Eye Position

Knox and Leavitt (1977) reported that the magnitudes of (see Fig. 1) z_e (the vertical deviation the airplane may be below the path with pilot's eye looking directly at rear of shadow path) and z_s (maximum height that the airplane may be above path before shadow disappears from bottom of display) for a given FOV vary the size of airplane symbol, shadow and path by moving the airplane closer or farther away from the viewing screen, affecting the degree to which the top and rear of the airplane symbol is displayed to the pilot. It was subjectively determined by the authors during initial display development that the value of the parameter z_e can be 1 to 1.5 times that of z_s. The values z_e and z_s (their display format showed each to be 500 feet) are functions of the vertical-tracking-accuracy requirements. The magnitudes of these values, according to the authors, should be selectable by the pilot during actual flight operation. Knox and Leavitt (1977) suggest that a mode switch allow the pilot to select path capture, en-route tracking, and approach tracking options, and that during en-route tracking, z_e and z_s should be approximately 150 to 300m (492 to 984 ft), and during approach tracking, 30 to 90m (98 to 295 ft).

2.2.3 Coordinate Systems

Knox and Leavitt (1977) reported that the coordinate systems used in the generation of their Path-in-the-Sky perspective display (see Fig. 1) are represented by two reference axes systems--the Earth fixed axes system and the moving reference axes system. The Earth fixed axes system is an orthogonal system with the Z axis pointing toward the center of the Earth, while the X and Y axes are tangent to the Earth's surface. The moving reference axes system (X', Y', Z') is an orthogonal system attached to the aircraft's center of gravity. The X' (points toward horizontal direction of flight) and Y' axes remain in a plane tangent to the Earth, and the Z' axis points toward the center of the Earth. The moving axes do not rotate due to airplane bank, pitch or yaw angles.

The authors noted that the X' axis was fixed tangent to the Earth's surface for simplification of the computational requirements in the graphics computer. A potential drawback exists in that airplane maneuvers that require large (30^o) flight path angles could distort the display. However, the authors felt that, since this initial effort had been developed for transport-type aircraft, fixing the X' axis on a plane tangent to the Earth would not adversely affect the display development.

2.2.4 Symbology Construction

Various scaling and computer interface techniques used in the creation of the pathways, symbols, and textured surfaces of the flight path displays are described in the following three sub-sections. The scaling of each will be addressed first within each sub-section, followed by a discussion of applicable computer interface techniques.

2.2.4.1 Pathways

a. Path width is independent of all other geometric parameters, according to Knox and Leavitt (1977). The width must be specified (see Fig. 1) to allow the pilot to clearly view airplane, shadow, and path symbology interactions. Reduced path width, however, allows for detection of smaller path deviations, hence higher precision path tracking. The authors used a path width of 400 feet for their display format.

Symmetric and equal guidance components were set up on both sides of the "street" in Wilckens' (1973) display (see Fig. 12, below).

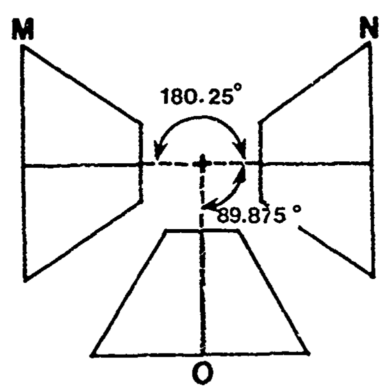


Figure 12. Guidance Components Used in the Construction of Wilcken's Channel Display (from "On a Solution of the Residual Problems of Aircraft Control Especially in Zero Visibility Landings by the Pictorially Quantitative and True Perspective Channel-Display", V. Wilckens, Berlin, Germany, 1973).

The scale properties of half of the extended angle ¶ → ¶/2 allows for more precise control. The aircraft (or, to be more precise, the pilot's head) moves exactly along the nominal flight path if the perspective angle between the center lines of M and N is extended to equal ¶ = 180.25°; the center line of the street is perpendicular to this (dashed lines in Figure 12 added by author). The center lines serve to display nominal deviations in the plane corresponding to them, and provide optimal sensitivity in the other plane.

The next step involves combining the three identical information elements into a single one. Wilckens (1973) had not yet defined the most favorable signal sensitivity, to which the elements (MNO) of the nominal path are assumed to be matched, so he joined the three elements to form a channel-like symbol in which the areas were enlarged to opposite facing intersection lines. The width of the surfaces M, N, O specify important motion tolerance. The elements must be moved together. Thus, the author reported, the display sensitivity naturally changes for the vertical and/or lateral guidance, in accordance with the decrease of h_A. In other words, the parallel boundaries of the three elements display range (as does the centerline), and maintain the optimal sensitivity along the other axis. He suggested the possibilities of (1) closing the channel to a tunnel to avoid entering a neighboring flight corridor, or (2) omitting the upper halves of elements M and N when no upper limits of motion exist.

Wilckens (1973) advocated that fixed and strictly maintained tolerances for the three coordinates exist for the landing channel. The aircraft, he reported, must not set down ahead of the prepared runway (x-axis), next to the runway (y-axis), or hover under/above the runway level. The channel dimensions for the final phase include (1) the lateral tolerance limit, dependent on type of aircraft, runway width, and runway surroundings, plus (2) vertical tolerance limit, set by the center line and upper edge of the vertical element. On a firm basis, he reported, the width of the channel may be matched to the run-way. The maximum flyable glide angle is indicated via the upper half of the vertical information coı. c. During landings, he advocated, ±10M lateral maximum deviations were sufficient; during close formation flights and in-flight fueling, the deviations are about 1M. (Note: The practicality of flying close formation using a head-down display is negligible.)

The authors proposed the inclusion of a display of the trajectory vector, to represent the point track of the trajectory tangent in displays and in the surroundings. His reasons were that the attitude angles and flight trajectory tangents uncouple as the velocity decreases in rotating wing aircraft and other VTOL aircraft, and in less conventional aircraft (STOL), the deviations are larger. The channel renders the trajectory vector perceptible, in addition to providing for the high steering information discussed above.

In Wilckens' (1973) proposed display, the sensitivities of the errors which determine the trajectory control accuracy, controllability plus the display for the motion tolerances were rigidly connected with the dimensions of the channel cross-section. The channel dimensions, he reports, which represent the motion limits as dictated by the environment, must be accurate. He tested the effects of several combinations of widths and heights of the channel against various flight tasks using a constant ratio of H/W = 0.375:

W	Meters	20	40	80	240	480
H	Meters	7.5	15	30	90	180

Wilckens (1973) interpreted the results to mean that (1) with increasing miss sensitivity, and hence increasing stress on the pilot, the higher degree of difficulty of lateral control has a greater effect, and (2) requirements of the lateral control task increase compared with the elevation control task, and the lateral control allows an increased control activity compared with the longitudinal control with no detrimental consequences. He also found that the optimum of the miss average values for moderate degree of work is located at those channel dimensions required for correct lateral tolerance display during the critical end phase of landing.

Kraiss and Schubert (1976) conceptualized a channel (see Fig. 4) which would begin at a fixed distance of 100 meters in front of the aircraft, and reach 600 meters beyond. Lateral scaling, they decided, would be 200 meters and vertical scaling, 50 meters. Only the lower half of a tunnel was indicated, and commanded altitude was reached when the landing gear of the aircraft leveled out with the upper edges of the channel walls.

The perspective, earth-stablized commanded flight path in Wild's (1966) display (see Fig. 6) is capable of commanding all six degrees of freedom of motion, which enables it to display climbing and diving banked turns. The inputs for the flight path are its altitude and its north and east location with respect to some origin. The aircraft referenced flight director has inputs of altitude and lateral displacement. The flight path consists of three longitudinal strips. By deleting a selected portion of the center strip at a chosen location, a representative site on the path may be indicated.

b. During the drawing of the perspective path in the Knox and Leavitt (1977) display (see Fig. 1), the graphics computer simulation program keeps track of the airplane's (moving reference system) position and direction with respect to the Earth fixed axes. Internal computer algorithms perform the transformations required for drawing the perspective path on the viewing screen.

Stroke writing techniques for the Kraiss and Schubert display (see Fig. 4) were applied for the implementation of the channel display on a CRT screen. Twelve linear channel elements were lined up, bent paths being approximated by straight lines. Some hidden-line removal and area-hatching techniques were applied to avoid the effects of the channel appearing to "tilt over".

The (LaRussa, circa 1960) Farrand Path-in-the-Sky display (see Fig. 2) symbology is scaled according to the geometric equations illustrated below. Although technology has, in recent years, changed from the technology used to develop the Farrand display, the following information may contribute to an understanding of the concepts involved in its development.

The author presents a solution to the problem of producing the distorted path, or runway for projection into three-dimensional space (see Fig. 13):

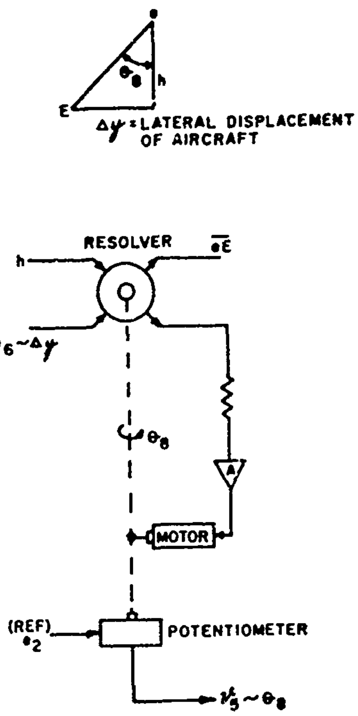


Figure 13. LaRussa's Solution to Producing the Distorted Path for Projection into Three-Dimensional Space (from "A Multi-Purpose Wide Field, Three-Dimensional Head-Up Display for Aircraft", J.A. LaRussa, Farrand Optical Co., Inc., Valhalla NY, circa 1960).

The apparent widths of the near and far edges of the runway are dependent on aircraft altitude, runway width and ranges to the near and far edges of the runway, as illustrated in Figure 14. LaRussa illustrates in the following drawing:

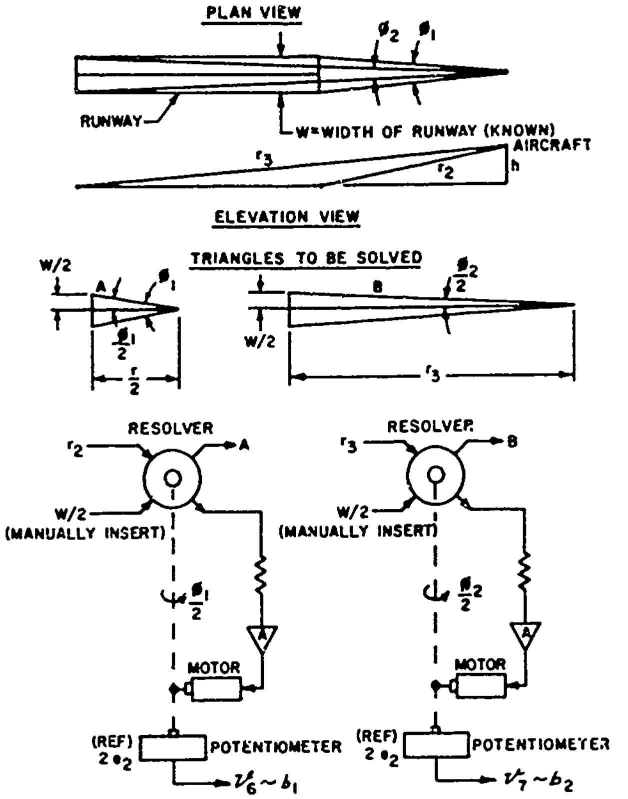


Figure 14. LaRussa's Illustration of the Relationship Between the Runway Size and Aircraft Altitude, Actual Runway Width and Ranges to the Runway (from "A Multi-Purpose Wide Field, Three-Dimensional Head-Up Display for Aircraft", J.A. LaRussa, Farrand Optical Co., Inc., Valhalla NY, circa 1960).

Figure 15 demonstrates the servo driven analog computers used in the Farrand display to solve the apparent angular size of the runway or path-in-the-sky based on aircraft distance above or below the glideslope.

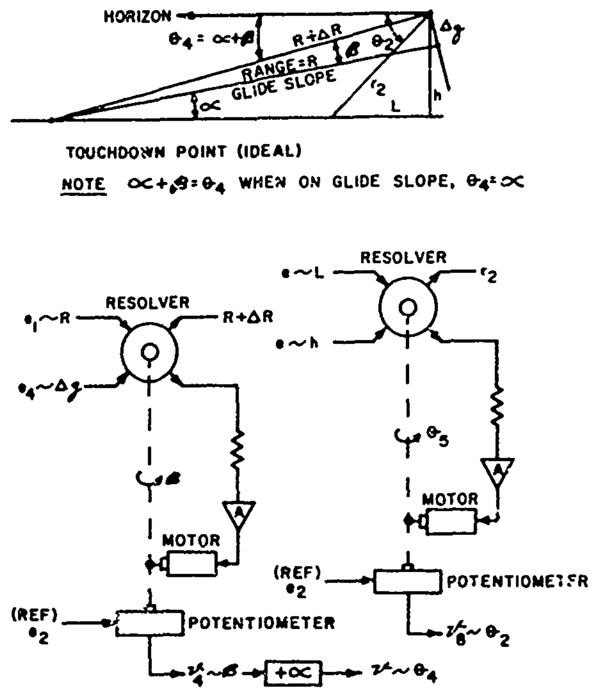


Figure 15. LaRussa's Solution to Creating the Runway Based on Aircraft Distance From Glideslope (from "A Multi-Purpose Wide Field, Three-Dimensional Head-Up Display for Aircraft", J.A. LaRussa, Farrand Optical Co., Inc., Valhalla NY, circa 1960).

The next figure illustrates a displayed condition, and the angles generated on the CRTs to form a final composite view of the Farrand display.

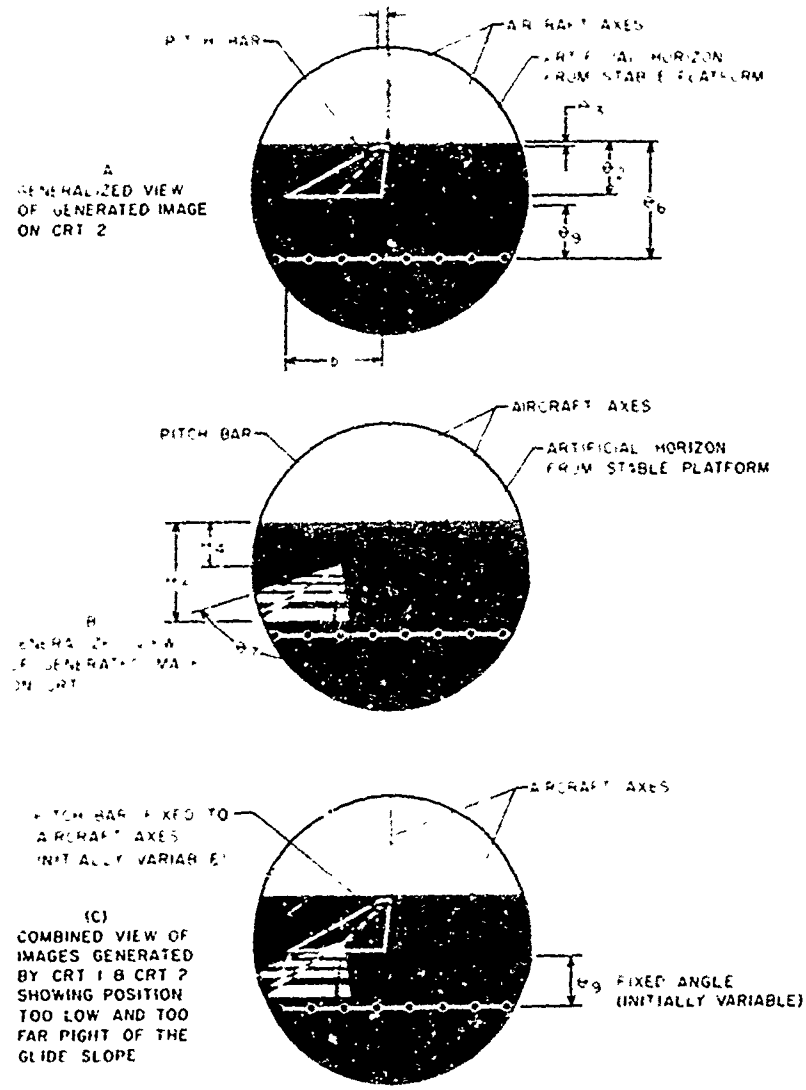


Figure 16. Displayed Condition and Angles Generated on the CRTs for LaRussa's Format Design (from "A Multi-Purpose Wide Field, Three-Dimensional Head-Up Display for Aircraft", J.A. LaRussa, Farrand Optical Co., Inc., Valhalla NY, circa 1960).

LaRussa (circa 1960) shows the generation of an increased angle of attack flight profile and resulting establishment of a glide slope with desired angle of attack, illustrated in the following figure:

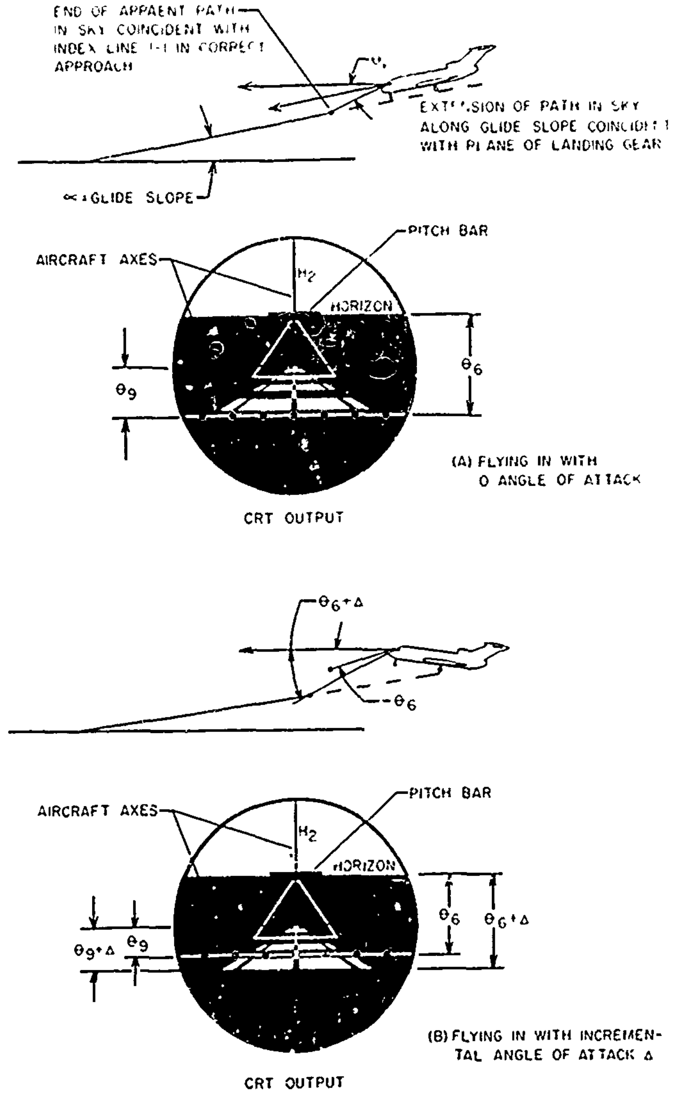


Figure 17. LaRussa's Solution to the Establishment of a Glideslope with Desired Angle of Attack (from "A Multi-Purpose Wide Field, Three-Dimensional Head-Up Display for Aircraft", J.A. LaRussa, Farrand Optical Co., Inc., Valhalla NY, circa 1960).

The technique used for Wild's (1966) display (see Fig. 6) with regard to generation of the flight path involves scanning out in a regular manner the reference surface, or model whose perspective image is to be computed. The display plane coordinates of the intersection of the ray and display plane for each point on the reference surface are computed. This method results in generation of the flight path.

2.2.4.2 Display Symbols

a. Aircraft symbol and shadow size, according to Knox and Leavitt (1977), must be adjusted to fit the path width (see Fig. 1). They suggested that the proportions be approximately 2/3 to 3/4 the width of the path, so that the illusion of going outside the path during turns does not occur.

Murphy, et. al. (1974 scaled the following symbols and parameters accordingly in the SAAB perspective display (see Fig. 8). Altitude error equaled 160 ft/in, airspeed error indicator equaled 33 knots per inch, the velocity vector symbol was represented at 20°/inch, the length of the reference height pole was 300 feet, and the circle for the altitude rate moved vertically 600 feet per minute per dot. The digital readings were scaled in knots and in feet.

Five non-perspective symbols may be simultaneously displayed in Wild's (1966) display (see Fig. 6), and are (1) an impact point or velocity vector symbol, (2) a weapons symbol, (3) an airborne target symbol, (4) a velocity cursor, and (5) two four-digit numbers. The impact point appears as a cross and is generated through the selection of the appropriate cells in an 8 X 8 matrix. A hollow square represents a weapon. A solid square, whose size varies as a function of range to the target, symbolizes the airborne target. A fixed and a vertically moving bar on a black background represent the velocity cursor. The display scaling for Wild's (1966) display is designed to enable variability of the geometric parameters. These include display width to height ratio, which may vary from 4:1 to 1:4, and ground plane scale, in which the size of each cell may be set to 4', 8', 16', 32' or 64'. The airborne target symbol texture (blocks or cell pattern) and size must be a minimum of one raster element square and a maximum of 32 raster elements square. All other parameters may be varied by a plug-in circuit card, by wiring, by a selector switch, or by programming, or in relationship to the dimensions of other symbols on the display.

Baty's (1976) three-display configuration (see Fig. 7) interrelated symbols and meaning across displays, and thus, he emphasized, it was important to make vertical and horizontal scaling compatible with the flight-path angle scaling.

b. The raster lines of the Wild (1966) display plane (see Fig. 6) are assumed to be parallel to the reference surfaces. Aircraft roll is then added to the image by rolling the raster (yoke of the CRT) as a function of real aircraft roll. Aircraft heading angle, pitch angle, north and east velocity, and altitude rate are inputs into the contact analog of Wild's display. The inputs are sampled each time frame, or 1/30 second. When the flight path is programmed as a flight director, the commanded inputs of heading, pitch, roll, lateral displacement, altitude error and velocity error are sampled each time frame.

2.2.4.3 Textured Surfaces

a. Wild (1966) reported that the structure of the ground plane (see Fig. 6) is defined as one of infinite extent, tangent to the earth's surface at the nadir of the aircraft. The surface is defined by a hierarchy of patterns, which consist of 4 orders of 64-cell matrices (8 X 8), each immersed in the next higher order pattern. Textures may be varied within each matrix. The runway plus one other unique location may appear on the ground plane. The runway is black and has a white dashed centerline; the other unique location, however, follows a 3-order pattern size, textured differently from the ground plane. The two obstacles, which may appear in the display, have variable location, height, length and width, but the sides (solid in color) must be parallel to a cardinal direction. The tops have textured surfaces scaled the same as the first-order ground plane texture.

In Wild's (1966) display, the sky plane appears parallel to the ground plane and at a fixed altitude above the aircraft, which responds to rotation about the three axes of the aircraft. It also contains 8 X 8 matrices whose pattern and spacing are variable. One matrix, texturally different from the sky plane, appears at the intersection of the nadir-zenith line and sky plane.

b. Wild's (1966) display (see Fig. 6) generates perspective pictures of a surface by computing the projection of the display raster pattern onto the reference surface. A ray originating at the viewing point passes through the display plane and intersects the reference system. As the ray is scanned in time across the display surface, computation of its point of intersection with the reference surface occurs, and is called the image of the scanning ray in the surface. The image's location depends on the altitude and position of the display with respect to the surface. The pattern on the reference surface becomes input data, is stored in the computer and called the map table. When the coordinates of the scanning ray image are determined, they are referred to the map table to locate the color of the reference surface at this point. The surface color is utilized to specify the drive to the electron guns of the CRT. This technique of computing the image of the scanning ray projected onto the reference surface generates the ground plane, sky plane, and obstacle top surfaces.

2.3 Human Factors Requirements

The literature reveals findings from studies which are intended to assess the pilot's capabilities and needs to safely and accurately fly an aircraft using a pictorial (such as flight path) display. These findings are referred to herein as human factors, or pilot factors.

2.3.1 Display Symbology

Wilckens (1973), after whose model Kraiss and Schubert designed their channel display, addressed thirteen requirements (pp. 1-4) of display symbolism, which are:

1) The display system must free the pilot from the pressure of having to formulate a mental picture from information imparted intermittently;

2) The final phase of landing requires particularly sensitive information because of its narrow range;

3) Signal sensitivity must be useable by the pilot;

4) The system should enable easy, precise guidance;

5) The pilot should be able to freely choose the approach flight path if he sees the available space for maneuvering;

6) The content of the statements of the overall information should change only under extraordinary conditions;

7) Information characteristics of higher order should be used for displays of obviously higher priority;

8) The information display should include and maximally develop the strong human capabilities for controlling complicated dynamic systems with almost artistic perfection;

9) The flight training requirement should be based on constant practice, even though flight is largely automatically guided;

10) Symbology should (whenever possible) be applicable to all flight phases;

11) The natural capability of graphic types of information to signal system failures should be utilized;

12) The sensation of motion should be used to enhance the system; and

13) The display information should instill confidence in the pilot.

Wilckens (1973) advocated that the "form" of information must be treated with first priority in attempting to satisfy all thirteen (13) conditions; however, he reported that Beyer listed "optimalization of the display symbolism" last on a five priority scale.

With respect to judging flight path perspective, Wilckens reported that straight-line visual approach is not easier to master than curved visual approach, as some people have assumed.

2.3.2 Visual Perception

In attempting to develop a flight path display (or any cockpit display), certain visual perception factors regarding the interface of man and machine must be considered.

Carel (1961) investigated perceptual responses based on laboratory (non-simulator, nonoperational flight) experiments with respect to contact analog display features. He (later) defined a contact analog display (1965) as "the point perspective projection of a three-dimensional model to a picture plane".

Carel (1961, pp. 29-30) reported that: (a) The accuracy with which <u>pitch</u> is judged is independent of the shape and size of the texture pattern, is partially dependent on the density of the optical pattern, is greater for unbroken patterns than for random or irregular patterns, increases with increasing aperture size, does not increase with the addition of forward motion when a regular periodic line pattern is used, and increases with the condition of forward motion when an irregular pattern is used. In general, according to Carel, the accuracy with which pitch is judged decreases with increase in pitch. (b) <u>Velocity change and direction</u> can be detected within six percent accuracy. (c) The accuracy with which the <u>collision point</u> can be estimated by a pilot increases with the increase of the V/h ratio (V = velocity, in feet per second, h = height, in feet). (d) The accuracy with which the time-to-go can be estimated by a pilot increases with increase in the V/h ratio. (e) Surface separation (determining which surface is "closer" or "in front") can be achieved by manipulating image brightness and image sharpness (i.e., ground should be less bright or in less focus).

Orientation is dependent in part on visual cues, according to Carel (1953). Orientation refers to four attributes of perception as indicated by judgmental behavior with respect to (a) aircraft body position with respect to the earth's surface; (b) direction of movement; (c) speed of movement; and (d) direction and ordinal position of objects in the visual world.

Carel (1961) reported that in order to secure orientation, a display must comprise (a) a textured surface, (b) a horizon, and (c) motion perspective (p. 5).

Carel (1961) offered a list of the visual configurational aspects (pp 6, 7) of experimental variables (images and flight conditions) to be considered when evaluating an analog display. These are:

A. Image/Objects

1) Complete replication of a sample of a real earth's surface
2) Random distribution of varying size dots on the surface
3) Equally spaced parallel lines on the surface
4) Equally spaced parallel lines at right angles to each other on the surface
5) Checkerboard arrangement on the surface

B. Flight Conditions

1) Speed and rate of change of speed
2) Pitch and rate of change of pitch
3) Roll and rate of change of roll
4) Rate of climb/dive
5) Turns
6) Wind drift effects

The results, he stated, which must be looked for are functions and errors of recognition of changes in velocity, altitude, pitch, roll, and turn, recognition of point of impact, plus other qualitative orientation errors.

Carel (1954) reported that one of the first things a pilot needs to learn in instrument flight is to suppress most known forms of "tracking behavior". These natural inclinations must be overcome, to be substituted by some conceptual scheme generated by information presented on the instruments. Since the link which exists between instruments and controls is a highly complex cognitive process, the solution to the tracking data question may lie in one of two contrary directions: (a) design the display so that "natural" tracking behavior will be effective, or (b) design the display so that cognitive schemes will be quickly built up.

According to Carel, it is difficult to determine whether a system of instrumentation is ineffective because the information types are incorrect, or merely because the displays are incorrect.

Emery and Koch (1965) investigated pilot performance of simulated rotary wing maneuvers under three display conditions which augmented the JANAIR contact analog vertical display with numeric information about altitude, heading and airspeed. These three conditions included moving tape scales, moving pointer scales, and digital readouts, each presented with the basic grid plane, and compared with each other and with the basic grid plane without the numeric information. Results indicated that numeric information added to the display significantly ($p < .01$) increased pilot performance when compared with the basic grid plane alone. Of the three methods of displaying numeric information, superior performance was exhibited using the moving tape scales or moving pointer scales.

Kraiss and Schubert (1976) found that when predictor information was removed from their displays, no significant differences between the two- and three-dimensional formats were found (see Figures A1 and 4, respectively). The authors noted with regard to this portion of their study, that even with extensive training without the predictor, no subject was ever able to reach the same score as with the predictor. Thus, the authors concluded, predictor information could not be adequately substituted by either type of display alone.

The contributions of the real-world cues of runway outline in the Eisele, et. al. (1976) displays (see Figures 5 and A2) increased at far ranges from the touchdown aimpoint, and runway centerline cue increased at near ranges. Also, the touchdown zone markings did not contribute significantly to the overall accuracy or speed of judgments and the presence of the texture grid was accompanied by slower judgments and at medium range, more incorrect responses in the vertical dimension. Statistically reliable interactions between visual elements indicated that the presence of the runway outline contributed less when the "highway" was present than when it was absent from the display, that the texture grid enhanced performance when the runway outline was present, but decreased performance when the touchdown zone markers were provided, resulting in slower responses when the runway centerline was absent.

2.3.3 IFR/VFR Transitioning

Transitioning between head-up (real world) visual flight and head-down instrument flight creates hardships for the pilots. When additional problems (heavy precipitation, fluctuation in ambient light, wind shear, smog or haze) are introduced, the pilot's workload increases, due to the necessity for more frequent visual switching between real world and instrument flight (Shrager, pg. 1). This section is an over-view of findings which point to the difficulties encountered by pilots when it becomes necessary to transition between visual flight rules (VFR) and instrument flight rules (IFR); the cited statistics aid the argument in favor of a display system (e.g., flight path displays) which frees a pilot from the burden of these constant visual and psychological transitions by allowing (if properly designed) the pilot to fly using the display exclusively.

Hanes and Ritchie (1965) identified two types of display problems with regard to approach and landing during reduced weather minimums (low ceiling, low visibility). These problems are associated with (a) display of information when transitioning from IFR to VFR during the approach, and (b) display of information under conditions where visual reference to the ground prior to touchdown is not possible. Accuracy is a major concern during approach and landing, and the time required to accurately assess flight situation and initiate the appropriate control movement is important also.

Byrnes (cited in Hanes and Ritchie, 1965) reported in studies regarding response time lag of pilots, that the total time taken from clear distance vision to read a dial located on the instrument panel with recognition and return to clear distance vision is about 1.5 to 2.0 seconds. Travis (cited in Hanes and Ritchie, 1965) found that it took 1.06 seconds (average time) to fixate near and far stimuli successively, and make both verbal and motor responses; also, the average time for accommodation and convergence alone in refixation of near and far stimuli was 0.20 seconds. Wuefeck, et. al. (cited in Hanes and Ritchie, 1965) estimated that it takes 2.39 seconds to shift sight from outside the aircraft to the instrument panel and back.

Factors which may affect eye-movement, according to Hanes and Ritchie (1965), are visual field, motion, duration intensity, spectral composition, visual angle, spatial arrangement of the signal, head and eye movements between the panel and the outside world, and lighting factors.

Jenks (cited in Hanes and Ritchie, 1965), in research which studied mechanical lag, found that it takes from 4.5 to 7 seconds (using autopilot at a ground speed range of 129-171 mph) after the pilot moves the control to initiate a turn until the aircraft shows a measurable departure from track. Calvert and Sparke (cited in Hanes and Ritchie, 1965) reported time-distance ratios for correcting maneuvers (flight tests conducted in prop-driven aircraft) increased geometrically.

Ellis and Allan (cited in Hanes and Ritchie, 1965) they reported, found that in studying eye movement during the last thirty (30) seconds of VFR approach, eleven (11) pilots on the average looked outside the aircraft 56% of the time, at panel instruments 32% of the time, and transitioned between the two 12% of the time.

Hanes and Ritchie (1965) found in a pilot survey that 83% of the pilots reported they preferred a combination ground control approach and instrument landing system (i.e., ILS approach with GCA monitor) to either alone for cross checking capability. The tendency of central computers and complex displays is to reduce redundancy of information, they reported; however, the capability for accuracy verification is reduced. They suggested the use of uncollimated windscreen displays to counteract this effect, as greater precision of display may be possible since display size may be larger than on the panel. Adverse effects of this solution, they warned, could surface in optical absorption, object obscuration, and reflection.

SECTION III

FLIGHT PATH DISPLAY RESEARCH: FLIGHT PATH VS. NON-PATHWAY DISPLAY COMPARISON STUDIES

Studies which have been done comparing pilot performance using flight path displays and non-pathway displays are discussed in the following section. Tables 3 and 4, which summarize the results of these studies, are provided to simplify comparisons between display capabilities.

3.1 Fixed Wing Aircraft Displays

The two experimental studies described below evaluated flight path displays designed for use on fixed wing aircraft.

3.1.1 Three-Dimensional Channel vs Two-Dimensional Display; Kraiss and Schubert

The authors (1976) tested ten subjects (all non-pilots) using a fixed base Fouga Magister cockpit simulator, acquiring both objective performance data as well as subjective responses (see Table 3), in three experiments designed to assess the relative advantages of two-dimensional and three-dimensional "channel" display formats (see Figures A1 and 4, respectively). The two types of displays used in these experiments were (a) instrumentation with three two-dimensional display formats including Vertical Situation Display (VSD), Profile Situation Display (PSD), and Horizontal Situation Display (HSD), and (b) instrumentation with one three-dimensional pseudo-perspective display format. Experiment 1 compared accuracy in flying a complex mission profile. Experiment 2 was designed to determine speed of orientation in space and asymptotically flying onto the command path, and to assess differences in flight strategies between the two displays. Experiment 3 was designed to test display capabilities during turbulance, to assess the importance of predictor information in both displays, and to examine eye point-of-regard measurements.

3.1.1.1 Experiment 1

a. Results from this study concerning accuracy in flying a complex mission indicated that the three-dimensional display was flown seven to nine meters too high depending on the mission profile, which is representative of about 1/5 of the channel wall height. The two-dimensional display showed a consistent error of only two meters over the whole mission. The authors attributed the error made with the three-dimensional format to visual perception, since, they said, the channel does not give sufficient cues for the pilot to judge his altitude, which may have mislead subjects as to the channel zero position. The authors advise that a redesigned channel might avoid this systematic error.

The average lateral deviations are statistically the same for both formats. However, in curved mission segments the three-dimensional format produced errors of 35 meters (about 1/6 of the channel width), as compared to the two-dimensional format, which produced errors of only 3 meters. The error with the channel display was noted to have been always directed toward the inner side of a curve (right or left), the reason being, the authors suspected, that the subject, as trained by his daily driving experience, felt as though he were actually driving on a road, and so approached the inner border of the "street" when flying a curve, thus leaving the centerline.

In measuring the radial deviation from the command path, only during transitions from curved to straight mission segments was the three-dimensional display significantly better than the two-dimensional format. Other mission segments showed the same tendency, but were not statistically significant. Additionally, a significantly higher roll angle variance was found with the two-dimensional display. These findings led the authors to conclude that subjects had more complete control over the aircraft on curved paths when flying the channel display.

b. Subjects reported feeling more stress when flying the two-dimensional display, but thought its accuracy to be superior. However, the three-dimensional channel was felt to be more realistic, and allowed for a far quicker and simpler orientation. Display quality was felt to be sufficient for both types of displays. Four of the ten respondents reported that they felt vertical position information was inadequately presented, which was reflected in the above stated objective findings regarding average vertical deviations.

3.1.1.2 Experiment 2

Results of the second experiment indicated that a quick and smooth approach to the command path could be made in all cases. However, with the two-dimensional format, subjects tended to overshoot in lateral direction before finally approaching the command path asymptotically. The same behavior was seldom observed with the three-dimensional display. Quick orientation was also simple with both types of displays. Subjects reported having some difficulties flying exactly onto the curved path using the three-dimensional display. Maintaining zero deviation over long periods of time created difficulty, and caused tendencies to oscillate. They suggested this tendency may have been due to the dynamics of the predictor being slower on the channel display than on the two-dimensional display; the resolution of the predictor information was worse in the three-dimensional display because a perspective presentation assumes a reduction of size for objects far away.

3.1.1.3 Experiment 3

a. In determining display effect when stabilizing the aircraft against heavy turbulances, the authors found that no large differences could be observed. Their findings supported the theory proposed by Knox and Leavitt (1977), which said that a reduction in scan pattern (and hence, workload) would occur with use of a contact analog display. Kraiss and Schubert (1976) discovered that with predictors in the displays, eye point of regard measurements showed that, using the three-dimensional format, pilots looked steadily to the center of the channel, finding all needed information at or around this fixation point. Using the two-dimensional format, subjects sequentially checked profile and horizontal situation in a regular manner. Almost no attention was paid to the vertical situation. When predictors were removed from the displays, the scanning pattern over the three-dimensional display remained unchanged except to become more scattered due to larger deviations of the observed channel. The two-dimensional format (without predictor), however, forced subjects to alter their scanning behavior by scanning sequentially all three parts of the display.

b. The subjects reported that, over a period of thirty minutes, scanning the two-dimensional display was extremely tiring. No complaints were made in this regard about the three-dimensional display.

3.1.1.4 Summary

The results of the Kraiss and Schubert (1976) study, the authors said, indicate a need for further display development and testing of the new display to attempt to correct the channel, which they felt attributed to the systematic errors in maintaining a commanded height.

3.1.2 Glideslope/Localizer Path Display vs Non-Path Display; Eisele, Willeges and Roscoe

The authors investigated (see Table 3) synthetic imaging displays with respect to the isolation of minimum sets of visual cues sufficient for spatial orientation in ground-referenced aircraft landing approaches. TV-projections of static computer-generated images containing thirty-two various combinations of skeletal symbology from various positions and attitudes during final approaches to landings were compared.

Lateral and vertical orientation deviations relative to a four-degree glideslope and localizer path were measured and analyzed. The thirty-two displays developed by Eisele, et. al. (1976) contained some combination of (a) four symbolic elements depicting real world elements (runway outline, touchdown zone, runway centerline, and a textured surface designated by a grid of "section lines") (see Fig. A2) plus (b) one synthetic element (a row of four T-bars of increasing height positioned along the approach centerline at 1/4, 1/2, 1, and 2 miles from touchdown aimpoint) (see Fig. 5) to provide a visual representation of an imaginary glidescope or localizer path. Also included in the symbology were touchdown aimpoint and horizon. The displays were shown in a manner designed to assimilate the experience of a pilot suddenly breaking out of an overcast on a final instrument approach to the runway, and the scene disappearing immediately following the pilot's response with no indication of erroneous or correct response.

3.1.2.1 Discussion

Results from the comparison study indicated that accuracy and speed of judgments were enhanced more by presence of synthetic guidance information (the roll of T-bars) than by the perspective projections of the four contact analog elements alone (the four T-bars indicating the "highway in the sky" allowed more rapid and quite precise position judgments).

3.1.2.2 Summary

Eisele, et. al. (1976) concluded that "the inclusion of guidance and/or prediction information in addition to the essential real-world elements in contact analog displays supports both rapid orientation and accurate control (p. 29)." They suggest that, due to the results of their study, an appropriate follow-on study would be the investigation of performance measures using dynamic flight path prediction symbology along with true-perspective contact analog scenes in the same displays.

Table 3

PILOT PERFORMANCE DURING SPECIFIED FLIGHT TASKS/MANEUVERS: COMPARISON BETWEEN FLIGHT PATH AND NON-PATHWAY DISPLAYS

Fixed-Wing Aircraft Displays

Flight Path Displays, Non-Pathway Displays with which Compared/Evaluated, and Authors	Vertical (altitude) accuracy with respect to the command path.	Average lateral accuracy with respect to the command path	Lateral accuracy with respect to command path during curved mission segments	Radial accuracy with respect to command path	Roll angle accuracy	Quick and smooth approach and orientation to command path	Tendency for overshooting in lateral direction when approaching command path asymptotically	Stabilization during heavy turbulances	Scan pattern (eye point of regard)	Accuracy of control during localizer tracking	Speed of judgements during localizer tracking	Pilot workload	Time to capture path
Three-dimensional vs two-dimensional, Kraiss and Schubert	<	=	<	>	>	=	>	=	>				
Glideslope/localizer path vs non-path, Eisele, Willeges and Roscoe										>	>		
SAAB perspective vs RAE transition display, Murphy, McGee, Palmer, Paulk, and Wempe										>		>	>
SAAB perspective vs TELDIX hover display, Murphy, McGee, Palmer, Paulk, and Wempe										>		>	<

> = Pilot performance using the Flight Path display, listed first, was significantly better than when using the non-pathway display, listed next.

< = Pilot performance using the Flight Path display was worse than when using the non-pathway display.

= = Pilot performance showed no statistically significant differences between displays.

3.2 Rotary Wing Aircraft Displays

The next four studies presented involve the evaluation of flight path displays designed for use in rotary wing aircraft.

3.2.1 SAAB Perspective Display vs RAE Transition and TELDIX Hover Displays; Murphy, McGee, Palmer, Paulk and Wempe

A fixed-base Bell UH-1B helicopter simulator was used to compare and evaluate (see Table 4) a SAAB perspective display, Royal Aircraft Establishment (RAE) proposed combined transition display, and the TELDIX hover display (see Figures 8, A3 and A4, respectively) for purposes of developing display concepts for application to V/STOL zero-zero landings (which differs from conventional takeoff and landing since the following requirements are assumed: steep and/or curved approaches at low and/or decelerating speeds; transition to hover; highly precise energy management; high density, time-constrained flight environments). Tracking performance, attitude variability, and control activity were measured for a straight-in approach with a command constant speed segment and a deceleration segment. Six pilots served as subjects, flying data runs with 6^{o} and 15^{o} flight path angles, with and without wind conditions.

3.2.1.1 Objective Results

Results from the Murphy, et. al. (1974) experimental study indicated that (a) for localizer tracking, the RAE display proved clearly less effective than the SAAB and TELDIX displays, and the SAAB display appeared to be more effective than the TELDIX display, (b) pilot workload was lowest with the SAAB perspective display and highest with the TELDIX display (the displays were ordered in effectiveness as follows: SAAB, RAE, and TELDIX, where the differences revealed localizer and roll variability measures significant for both the constant speed and decelerating segments and the sink and yaw measures significant only over the constant speed segment), (c) the authors speculated that the lesser effectiveness revealed by the SAAB display with respect to collective stick RMS activity over the decelerating segment was probably due to the lack of an artificial horizon indication for pitch cues, and (d) time to capture was shortest with the TELDIX display and longest with the RAE display. An adverse effect of wind on performance occurred with the RAE display; also, wind affected the localizer mean position over the constant speed segment more for the RAE display than for the SAAB or TELDIX displays. Localizer mean position over the decelerating segment was adversely affected by steep glideslope angle. The large localizer tracking errors, long time to capture, and adverse effects of wind or steep glideslope imply, stated Murphy, et. al. (1974), deficiencies in presenting lateral guidance information in the RAE display. Although the SAAB display permitted better localizer tracking than the RAE or TELDIX, time to capture was shortest for the TELDIX display due possibly, the authors surmised, to the relatively conventional cross-pointer presentation used in the capture process.

3.2.1.2 Subjective Data

Pilot opinion revealed a preference in favor of the RAE display over the SAAB display (which was at variance with the objective performance measures); the TELDIX display was given the lowest pilot opinion rating, due to the extensive central clutter on the TELDIX display. The only favorable comments given the TELDIX display were with respect to the presentation of horizontal position information.

3.2.1.3 Summary

The results of the study implied that the SAAB display provided lower pilot workload and/or better systems stability; however, pilot opinion was not in favor of the SAAB in this study.

3.2.2 Pathway and Pathway Plus Tarstrips Displays vs Non-Pathway Displays; Sgro and Dougherty

In a JANAIR report, performance measures were compared (see Table 4) for the basic helicopter flight maneuvers (low altitude, slow speed) of hover, takeoff and touchdown, and air taxi among four basic display configurations which included:

Display A - Basic grid plus an accented horizon line, haze layer and sky texture (see Fig. A5),

Display B - Basic grid plus a white ground stabilized square known as the ground position indicator (GPI) (see Fig. A6),

Display C - Basic grid plus a straight, white roadway or ground stabilized path (see Fig. 9), and

Display D - A display identical to Display C plus distance identifiers (tarstrips) along the path (see Fig. 10).

Sgro and Dougherty (1963) compared helicopter pilot performance using these particular displays where (1) the pathway provides direction information for flight courses on all headings; (2) the tarstrips allow for groundspeed estimates; and (3) the GPI is presented as a touchdown point. The task variables under which these four aircraft displays were evaluated included operational condition errors in assigned (1) altitudes of ten feet and fifteen feet, (2) groundspeeds of five knots and twenty knots, and (3) heading. Separate and combined scores for these conditions were analyzed. A dynamic (motion-based) simulator (whose cabin was a Bell model 47-J cockpit) was used for the experiment, which was capable of responding with six degrees of freedom. The platform limits of travel for the simulator's three angular motions were 10° of pitch, roll and yaw. Maximum acceleration was 40° per second for pitch, 60° per second for roll, and 15° per second for yaw. Vertical motion of the Bell UH-1A helicopter was the only motion dynamically simulated. The limits of travel were $\pm$ 3.5 feet; the maximum acceleration was 6.5 feet per second.

3.2.2.1 Experiment 1: Hover Maneuver

Results indicated that with respect to the execution of basic hovering maneuver tasks where the pilot was required to hold an assigned heading and altitude, performance measures of heading error showed Display C demonstrating superior performance ($p < .05$) to the other displays when the pilot had to maintain 10-foot and 15-foot altitudes (exception: Displays C and D showed no differences for conditions requiring the pilot to maintain a 15-foot altitude) and when the combined scores for all assigned conditions were considered. Significant differences in altitude error data were found ($p < .01$) between displays when a 0-degree heading was required, with Display D demonstrating the least errors, and Display C the next fewest number of errors. Display D differed at the .125 level from all displays except Display C.

An analysis of the right-lateral positions revealed significant ($p < .05$) differences between displays for all experimental conditions combined; Display A yielded inferior performance, whereas Displays B, C, and D were not statistically different. For left-lateral position, no statistical differences were found between displays. An analysis of the combined error for left and right lateral error scores showed Display C yielded the best performance (1) during conditions involving an assigned 30° heading ($p < .01$) and (2) for the combined total of all experimental conditions ($p < .05$). Exception: Displays C and D showed no difference under the assigned condition of 30° heading but differed (Display D was superior to Display C) when all experimental conditions were analyzed ($p < .125$).

Fore position error data revealed differences ($p < .05$) between displays for conditions involving an assigned altitude of fifteen feet, showing Displays A and D to be superior in performance. Display D differed ($p < .125$) from B and C, and Display A differed ($p < .125$) from B. No statistical differences appeared between displays for the performance measure of aft position, or for the combined fore-aft position.

Combined responses under each display revealed no significant differences.

3.2.2.2 Experiment 2: Takeoff, Hover, and Touchdown Maneuver

Sgro and Dougherty (1963) compared the performance errors for the four displays during a takeoff, hover, and touchdown maneuver in which the pilot was required to hold an assigned heading. They reported heading performance deteriorated for all displays under an assigned 30-degree heading. Also, Display A proved to be significantly superior to the other displays with respect to vertical velocity for the conditions containing an assigned heading of 30 degrees. The authors stated that the simple grid plane appeared to offer more information for proper maintenance of vertical velocity (the squares in the grid pattern become relatively smaller as the aircraft increases in altitude and, conversely, the squares become larger as the aircraft decreases in altitude).

Position at point of touchdown proved significantly different ($p < .05$) between displays for all experimental conditions combined, showing Display B to be superior. Sgro and Dougherty (1963) felt the ground position indicator provided positive information to the pilot, giving him maximum direction of displacement.

3.2.2.3 Experiment 3: Takeoff, Air Taxi, and Touchdown Maneuver

Takeoff, air taxi, and touchdown maneuvers were tested, in which the pilot was required to hold an assigned heading, altitude and groundspeed, and reported that statistically significant differences ($p < .01$) between displays for the combined conditions involving an assigned 30-degree heading were found, showing Displays C and D to be superior. Displays A and B exhibited the greatest variability for means and ranges of deviation scores during the conditions containing an assigned heading of 30 degrees. For the combined scores for conditions involving an assigned altitude of fifteen feet and an assigned groundspeed of twenty knots, and for the combined scores for all conditions, statistical differences ($p < .05$) appeared. Displays C and D were superior to A and B; however, Display C did not differ significantly from Display D.

Performance variability for altitude was greater under Displays C and D at the assigned altitude of ten feet than Displays A and B. When the assigned altitude was increased to fifteen feet, all displays exhibited extreme variability. No statistical differences were found between displays with respect to groundspeed.

Left-lateral position error data showed a significant ($p < .05$) difference between displays for (a) combined scores for conditions involving an assigned 30-degree heading, and (b) combined scores for all conditions, revealing Displays C and D to be superior to A and B. No statistically significant differences between displays were found for the performance measure of right-lateral position error data. Displays C and D proved superior with respect to the combined left and right lateral position error scores for (a) the combined scores for conditions involving an assigned 30-degree heading ($p < .01$) and for (b) combined scores for all conditions ($p < .05$).

No significant differences between displays were revealed for combined responses for hovering and takeoff, hovering and touchdown maneuvers.

Analyses for touchdown positions for 0-degree and 30-degree headings revealed that Display A, under a 0-degree heading, was inferior to the other displays ($p < .05$), and that under a 30-degree heading, Displays C and D were superior ($p < .01$), indicating, according to the authors, that the greater amount of information in the display, the better the touchdown performance.

3.2.2.4 Summary

Sgro and Dougherty (1963) concluded, based on their findings, that the displays using the pathway (Displays C and D) yielded superior performance to the non-pathway displays; however, the magnitude of error was small enough to warrant the use of any of the four displays.

The authors felt the need for, based on the results of their study, a speed marker moving along the pathway, since precision information had not been included in the generalized grid-type display or even from VFR flight conditions. In fact, Sgro and Dougherty extended their experiments beyond the previously discussed data collection and added an altimeter and an airspeed indicator to the cockpit; the addition of these instruments subsequently reduced the error for the performance measures of altitude and groundspeed, but in general an increase in error occurred for the other performance measures. The authors attributed this tendency to the possibility that the pilot's visual scan pattern was expanded to include the instruments, hence, insufficient time was permitted to monitor all parameters in the vertical display.

Although the JANAIR study reports only on low altitude, slow speed helicopter flight maneuvers, this research is especially interesting because Sgro and Dougherty (1963) compared performance errors between four different types of graphic displays rather than comparing performance errors between contact and non-contact analog displays. Additionally, these studies may be of consequence when evaluating displays for V/STOL aircraft.

3.2.3 Pathway and Pathway Plus Tarstrips Displays vs Non-Pathway Displays; Emery and Dougherty

Helicopter pilot performance was evaluated (see Table 4) during a JANAIR study using a flight pathway with and without tarstrips during climbout, low cruise and descent maneuvers. The experiment tested the same four display formats (see Figures 9, 10, A5 and A6) which were described and tested by Sgro and Dougherty (1963).

Three glideslope angles were selected for testing in the experiment: (1) six degrees climbout and approach; (2) eight degrees climbout and approach; and (3) fourteen degrees climbout and approach. Two headings were selected for study: (1) a cardinal heading representing 0 degrees; and (2) a 30-degree heading. The aircraft's heading was positioned prior to the flight, and the subjects were to attempt to maintain the set heading throughout flight.

The tests were performed using a dynamic simulator representative of the movements of a Bell UH-1 helicopter. Subjects (four helicopter rated pilots) were required to lift-off, air taxi, climbout, cruise, approach, hover and land over a given destination, requiring them to maintain heading, altitude, airspeed and glideslope.

3.2.3.1 Results

Results indicated that the climb airspeed error was significantly lower ($p < .01$) when using the pathway displays (pathway and pathway with tarstrips). No significant differences occurred between the pathway and pathway with tarstrips displays, however. Emery and Dougherty (1964) attributed these differences to the fact that one of the major cues for speed is the movement of the grid, and during climb, the interaction of speed and altitude is apparent. By adding a pathway to the display, the pilot was able to segment his rate of change of altitude from speed.

For approach airspeed, no significant differences in performance were discovered between the four displays. When evaluating pilot performance for glideslope angle error, Emery and Dougherty (1964) found the two pathway displays to be significantly superior ($p < .01$) to the non-pathway displays, illustrating the utility, concluded Emery and Dougherty, of the pathway in judging glideslope angles during approach.

Analysis of glideslope maximum vertical deviation showed significant ($p < .01$) differences were found between displays, indicating the basic grid plane (non-pathway) display, the pathway with tarstrips display, and the pathway display to be far superior to the basic grid plane with the ground position indicator (GPI). No statistical differences were found between the two pathway and the basic grid plane displays. According to the authors, the reason for this occurrence is that the relative size of the ground position indicator is affected by changes in altitude within each scale, thus creating difficulties for the pilot in judging glideslope position.

The hover fore/aft position, when tested, showed the pathway display to be statistically ($p < .01$) superior to the pathway with tarstrips display; there were no statistical differences, however, between the non-pathway (grid plane plus GPI) and pathway displays. No error could be recorded for the basic grid plane display since no information with respect to hovering was available on this display.

Hover lateral error was significantly higher ($p < .01$) for both of the pathway displays (again no error could be recorded for the basic grid plane display). There was no statistical difference between the two pathway displays. The authors suggested that the difference may have been due to the fact that the grid and GPI present more final position information, since the pathway is cut off at ten feet. No significant differences occurred between display formats when evaluating hover altitude error.

Table 4

PILOT PERFORMANCE DURING SPECIFIED FLIGHT TASKS/MANEUVERS: COMPARISON BETWEEN FLIGHT PATH AN

Rotary Wing Aircraft Displays

Flight Tasks/Maneuvers

Flight Path Displays, Non-Pathway Displays with which Compared/Evaluated, and Authors	HOVER: Heading maintenance at 10 ft, 15 ft altitudes	Heading maintenance at 15 ft altitude	Altitude maintenance at 0-degree heading	Right lateral position	Left lateral position	Left and right lateral position	Fore position	Aft position	Fore-aft position	Combined responses	TAKE-OFF, HOVER & TOUCHDOWN: Vertical velocity	Position at point of touch-down	TAKE-OFF, AIR TAXI, TOUCH-DOWN: Heading, altitude, ground speed combined (30-degree heading)	Heading, altitude, ground-speed combined (15-ft altitude, 20-knot groundspeed)	Altitude performance at assigned altitude of 10 ft	Altitude performance at assigned altitude of 15 ft	Groundspeed	Left lateral position	Right lateral position	Combined left and right lateral position	Combined responses for hover and take-off	Position at touchdown
Pathway vs grid plane, non-pathway, Sgro and Dougherty, Emery and Dougherty (JANAIR)			>	>	=	>	<	=	=	=	<		>	>	<	=	=	>	=	>	=	>
Pathway vs grid plane, plus GPI, non-pathway, Sgro and Dougherty, Emery and Dougherty	>		>		=	>		=	=	=		<	>	>	<	=	=	>	=	>	=	
Pathway plus tarstrips vs grid plane, non pathway, Sgro and Dougherty, Emery and Dougherty			>	>	=			=	=	=	<		>	>	<	=	=	>	=	>	=	>
Pathway plus tarstrips vs grid plane plus GPI, non-pathway, Sgro and Dougherty, Emery and Dougherty			>		=		>	=	=	=		<	>	>	<	=	=	>	=	>	=	
Pathway vs pathway plus tarstrips, Sgro and Dougherty, Emery and Dougherty		=	=	=	=	<	<	=	=	=	=	=	=	=	=	=	=	=	=	=	=	=
Contact analog with pathway vs without pathway, Curtin, Emery, Elam and Dougherty																						

$\boxed{>}$ - Pilot performance using the Flight Path display, listed first, was significantly better than when using the non-pathway display, listed next.

$\boxed{<}$ - Pilot performance using the Flight Path display was worse than when using the non-pathway display.

$\boxed{=}$ - Pilot performance showed no statistically significant differences between displays.

* Sgro and Dougherty compared two pathway displays--one without tarstrips, and one with tarstrips.

ON BETWEEN FLIGHT PATH AND NON-PATHWAY DISPLAYS

ays

ht Tasks/Maneuvers

Tasks/Maneuvers						
... altitude of 10 ft	<	<	<	<	=	
Altitude performance at assigned altitude of 15 ft	=	=	=	=	=	
Groundspeed	=	=	=	=	=	
Left lateral position	>	>	>	>	=	
Right lateral position	=	=	=	=	=	
Combined left and right lateral position	>	>	>	>	=	
Combined responses for hover and take-off	=	=	=	=	=	
Position at touchdown	>		>		=	
CLIMBOUT, LOW CRUISE AND DESCENT						
Climb airspeed	>	>	>	>		
Approach airspeed	=	=	=	=		
Glideslope angle	>	>	>	>		
Glideslope vertical deviation	=	>	=	>		
Hover, fore/aft position		=		=		
Hover, lateral position	>	>	>	>		
Hover, altitude position	=	=	=	=		
Climb to altitude (airspeed, climbout mode, lateral and vertical track control)						=
Cross-country cruise track control (lateral)						>
Cross-country cruise track control (vertical)						=
Approach to hover/glide path track control						>

thway display, listed next.

2

3.2.3.2 Summary

The authors' interpretations of the data from this study emphasize the importance which a flight path and ground-related symbols play in enhancing the pilot's sense of visual perspective.

3.2.4 Pathway and Pathway Plus Tarstrips Displays vs Non-Pathway Displays; Curtin, Emery, Elam and Dougherty

In experimental flight tests conducted (see Table 4) in a UH-1 (Bell) helicopter for the JANAIR program, a contact analog (or vertical flight) display was evaluated. The study examined the basic grid plane with and without a flight pathway (see Fig. 11). Tarstrips and speed markers appeared on the pathway to indicate speed. During cross-country flight maneuvering a ground position indicator was displayed to indicate the final touchdown position. The grid plane and a remote altimeter indicated altitude to the pilots in the absence of the pathway.

The vertical display appeared above a horizontal display (slide presentations of a moving map, with a fixed aircraft symbol in the center of the display, always with heading up).

3.2.4.1 Discussion

The study investigated the performance of six helicopter pilots using displays with and without the pathway during a spectrum of basic flight maneuvers. Results from this study indicated that (1) for the climb to altitude, observer evaluations showed that no particular problems were encountered by subjects with respect to airspeed control during the climbout mode, lateral track control was unaffected by presence or absence of the pathway, and vertical track control was as good and/or slightly better when the pathway was not available (the tendency noted by Curtin, et. al. (1966) was for pilots to climb above the pathway and hold their position with the pathway beneath, enabling the pilot to see more readily the path; without the pathway this relative difference was not as great); (2) for the cross-country cruise, track control with the pathway was maintained within ± 870 feet; without the pathway, lateral track error increased to an average of ± 1728 feet; cruise airspeed control was not significantly affected by the presence or absence of tarstrips or speed markers on the pathway; pilots averaged ± 112 feet vertically from the pathway, and experienced momentary deviations of ± 147 feet from the commanded flight path without the pathway; and (3) for the approach to hover, glide path track control decreased severely when the pathway was removed from the display. Subjective data acquired through questionnaires confirmed these findings.

3.2.4.2 Summary

One of the problems encountered with flight path displays which was noted in this study, is one which deserves special attention, particularly when considering future flight path display development. Pilots tended to climb in altitude to a position where they felt they could "view" the path below them. Particularly during landing modes this tendency could create problems; redesign of the display might be required to effect better pilot performance.

3.2.5 Section Summary

In summary, the above results permit the following generalizations:

Pilots showed, in simulated flight tests using fixed wing aircraft displays with flight paths, superior performance for radial and roll accuracy, lateral direction when approaching the command path asymptotically, control accuracy and speed of judgments during localizer tracking, and time to capture path, plus reduced scan pattern and workload, than when using non-pathway displays.

Pilots showed, in simulated flight tests using rotary wing aircraft displays with flight paths and textured surfaces, superior performance for heading, altitude, groundspeed and airspeed accuracy, left and combined left-and-right lateral position accuracy, fore position accuracy, position at touchdown, and glideslope angle accuracy, than when using non-pathway displays.

Additionally, inferior pilot performance when using the flight path displays was observed for:

(a) altitude accuracy, only when textural background did not accompany the pathway;

(b) lateral accuracy during curved mission segments, in which pilots tended to counteract for curves in the command path by banking toward the outer edge of the pathway (as one might do when driving a vehicle around a sharp, banked road curve) rather than maintaining flight down the center of the pictured path;

(c) time to capture path, when the flight path display was compared to a non-pathway display using bank and pitch steering bars;

(d) fore position, when compared to a textured display with a ground position indicator, and when compared with another pathway display which also included tarstrips on the path;

(e) vertical velocity, when compared to a display which did not incorporate a ground position indicator; and

(f) position at point of touchdown, when compared to a grid display with a ground position indicator.

These findings point to the importance of a pictorial pathway, a textured background, tarstrips on the path, and ground position indicator as visual orientation, perspective and closure cues in display symbology.

SECTION IV

CONCLUSIONS

> "It is by facilitating (the pilot's) intelligent action in the face of opportunity or adversity that pictorial situation displays...may contribute most directly to flight safety and mission success."
>
> Eisele, et. al., 1976, p. 33

The following conclusions have been drawn, based on the preceding references:

1. Flight path displays have the potential ability to provide the pilot with visual cues such as perspective, orientation, and closure, whereas non-pathway displays do not.

2. The presence of a pathway, a textural surface, path predictor, speed markers (tarstrips) along the pathway, a touchdown symbol (ground position indicator) and moving scales for heading, altitude and airspeed serve to enhance the information display.

a. The use of a pictorial flight path allows the pilot greater reliance on the display for orientation and frame of reference during adverse weather or darkness.

b. The use of symbols arranged in a configuration which appears analogous to the real world depicts relative movement rather than specific facts, which removes some of the need for the pilot to mentally compute figures in order to assess his flight situation.

c. The incorporation of a textural background into the flight path display enhances pilot performance by increasing visual perspective.

d. Path predictor information cannot be adequately substituted by either a flight path or non-pathway display alone.

e. Tarstrips on the pathway (horizontal lines parallel to the horizon) are instrumental in enhancing display information with respect to fore position.

f. Position at point of touchdown is enhanced via a ground position indicator.

g. Presenting numeric information such as heading, altitude, or airspeed via moving tapes or scales enhances display information.

h. Moving pointer scales, or moving tape scales as methods of providing numerical information, allow greater accuracy than digital readouts.

3. Structural features with respect to the format and geometric design of a cockpit display elicit certain response tendencies from the pilot.

a. Pilot performance does not differ when comparing thirty- and sixty-degree fields of view.

b. Airspeed control is significantly enhanced when using a 12" square screen as opposed to a 6" square screen.

c. Final touchdown position is significantly more accurate when using a 6" square screen rather than a 12" square screen.

d. The presence of bank and pitch steering bars on a display allows pilots to capture the command path in less time than the pictorial pathway.

4. Lateral and vertical displacement is not as critical during cruise control as it is during approach and landing. In order for a flight path display to be effective during approach and landing modes as well as during cruise modes, the scaling of a flight path display requires special attention.

5. The natural tendencies of steering (as learned from driving experiences) can be effectively utilized with a flight path display to reduce the amount of time and money spent in training and maintaining the efficiency of pilots.

SECTION V
RECOMMENDATIONS

Based on the previously stated conclusions with respect to flight path displays, the following recommendations are offered for consideration:

1. Flight path displays should be evaluated against those display systems which are currently in wide use. Studies cited in this report were designed to assess the validity of features within flight path displays; however, in so doing, they compared flight path displays only to systems which were merely conceptualized and/or little used, and these findings are of less practical value to researchers than if the flight path displays were compared to those systems presently used and accepted. The recommended approach would enable a judgment as to the advisability of proceeding with research and/or developing for use the proposed flight path display concept.

2. An ideal display should incorporate the following symbology: command flight path, textural background, path predictor information, speed markers (tarstrips), a touchdown symbol, and moving numerical scales for heading, altitude, and airspeed information.

3. Flight path displays should be designed so that they are adaptable to various modes of flight.

a. Scaling techniques for various flight modes should be incorporated into flight path displays in order to compensate for human abilities with respect to man-machine interface.

b. Transitions to new modes of flight should be enhanced by signaling the pilot through the use of configuration changes to the aircraft symbol, of flashing symbols, and/or of color.

4. For approach and landing, the flight path display should be designed to address the problem wherein an aircraft and its display are too sensitive to the effects of wind and/or pilot control. The result of this oversensitivity is that the slightest displacement of the aircraft could potentially move the aircraft outside of the range of the flight path display, thus eliminating the pilot's frame of reference. This problem would be especially critical during adverse weather or darkness. Effective ways of dealing with this problem would be to:

a. Symbolically and operationally relate aircraft displacement from the runway in terms of runway width rather than degrees. This would tend to enhance the display in terms of its literal interpretation, thus more closely approximating the pilot's natural frame of reference.

b. Increase the degree of sensitivity during the final stages of landing approaching touchdown, and then at an appropriate point, allow it to decrease or remain constant.

5. Flight path displays portray perspective and closure to the pilot, whereas mechanical and electronic attitude director indicator/horizontal situation indicator display systems usually do not. Since results from studies evaluating flight path displays show that the presence of perspective, closure, and orientation cues enhance pilot performance, further investigations into the implementation of the flight path display concept are deemed viable and desirable actions for future display research and development.

6. Figure 18a illustrates an integrated flight path display format conceptualized on the basis of information and impressions derived from the preceding referenced displays and evaluation studies. This proposed flight path display may appear either on a head-up or head -down display. It consists primarily of a three-dimensional perspective channel and an aircraft symbol. The aircraft symbol is a stationary symbol, and the channel moves about it with changes in lateral and vertical direction.

The option exists for various elements of information (symbols, numerical readouts, scales, etc.) to be selectively displayed or eliminated from the format by use of a declutter switch.

The pilot's task requires him to guide the aircraft symbol through the center of the channel in order to accurately stay on course. When the pilot is flying the command path, the channel floor and the wings of the aircraft symbol will appear parallel and horizontal. The tail of the aircraft symbol will align with the channel's centerline indicating lateral accuracy, and the wings will align horizontally with the altitude reference lines on either side of the channel's entrance, indicating vertical (altitude) accuracy.

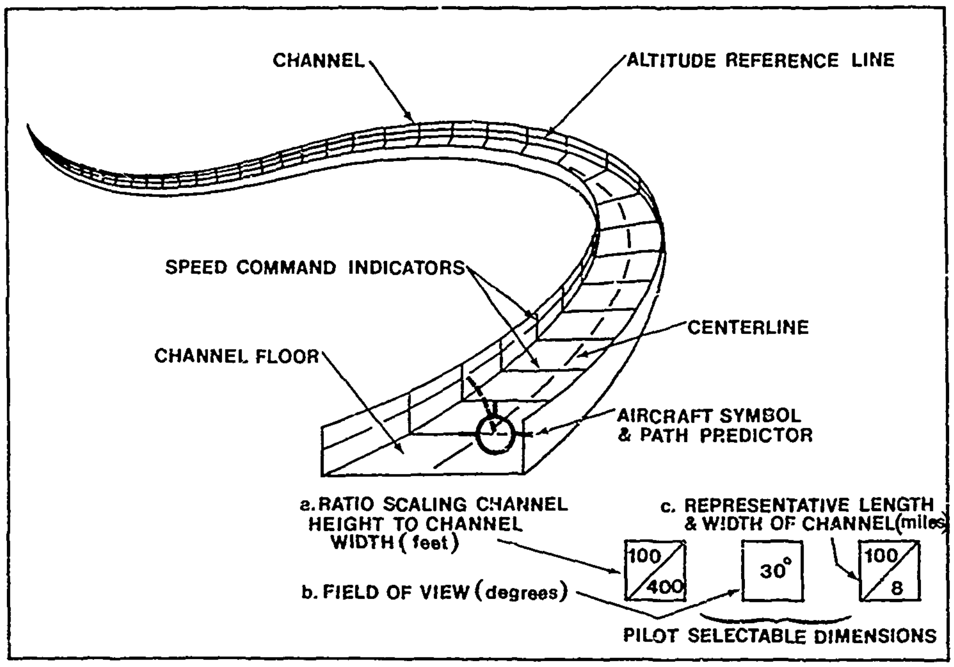


Figure 18a. Proposed Flight Path Display: Channel Configuration Depicts Aircraft to be Slightly to Right of Command Path, but Flying the Command Altitude. The Aircraft is Heading Slightly to the Left, as Indicated by the Path Predictor.

The inner and outer channel walls contai. vertical line segments perpendicular to horizontal lines on the upper (inside) view of the floor. The floor lines are perpendicular to the centerline. These line segments serve as (1) a speed command indicator (via a strobing effect) and (2) an aid to pilot visual orientation with respect to the aircraft symbol and the channel. The aircraft symbol is augmented by a dashed line path predictor. Each of the four consecutive dashes represents a time period of 10 seconds, indicating future aircraft position 10, 20, 30 and 40 seconds later if the aircraft were to maintain present flight conditions.

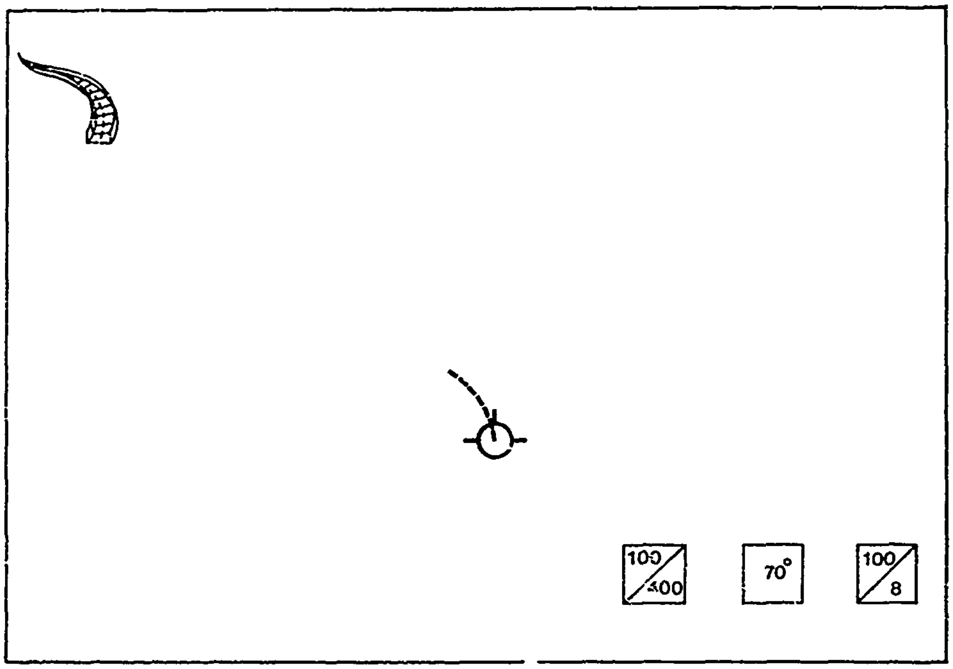


Figure 18b. Proposed Flight Path Display: Aircraft is Depicted as Being to the Extreme Lower Right of the Command Path, but Flying Toward it for Capture.

The channel extends into the distance so that upcoming curves in the path may be anticipated. The channel is designed to be viewed from all angles. This implies that even though the channel may appear in the form of a tiny configuration (see Fig. 18b) in a far corner of the display, indicating extreme lateral and vertical deviation from the path, or as a backward view of the entrance to the channel (see Fig. 18c), indicating that the pilot is directed 180° away from the command heading, some perspective of the channel would still be in view of the pilot and never completely disappear from the display surface. Thus, the inability to intercept the path due to a loss of display would never be a problem.

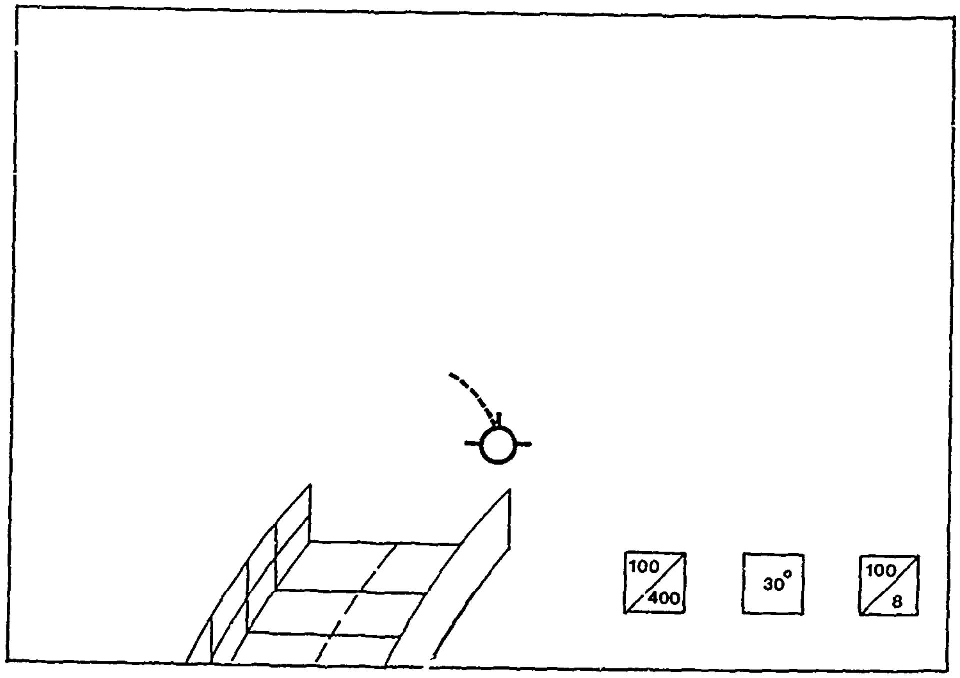


Figure 18c. Proposed Flight Path Display: Aircraft is Symbolized as Heading Away From (180°) Command Flight Path, but if Aircraft Continues Present Course (Extreme Left), it Will Eventually Capture Path.

If the display were to appear on a head-down CRT (as opposed to a HUD), the channel's inner and outer portions may be shade- or color-coded in some way that makes differentiating [illegible] easy for the observer. Questions arising with respect to the d[illegible] f orientation, then, could be answered more quickly, especially [illegible] ions from the command path are great, and the channel is [illegible].

The pilot may change the scale of several dimensions of the format via switch selection for the various maneuvers he will be required to perform throughout his flight. He may adjust: (1) the channel height-to-width ratio (the aircraft symbol remains fixed in size, regardless of channel or actual aircraft proportions); (2) the field of view; and (3) the length and breadth of the channel in terms of their representative dimensions. These dimensions would appear on the display at all times, and their values could be changed whenever the pilot deemed it necessary.

Information additional to the channel and aircraft symbol may be displayed (See Fig. 18d) on the head-down or head-up display by pilot selection. This information may include moving heading, altitude and airspeed scales all of which provide command indicators, current readouts, plus rate and direction of change. Also angle-of-attack and slip indicators may be made available on the display to enhance accuracy of flight path control.

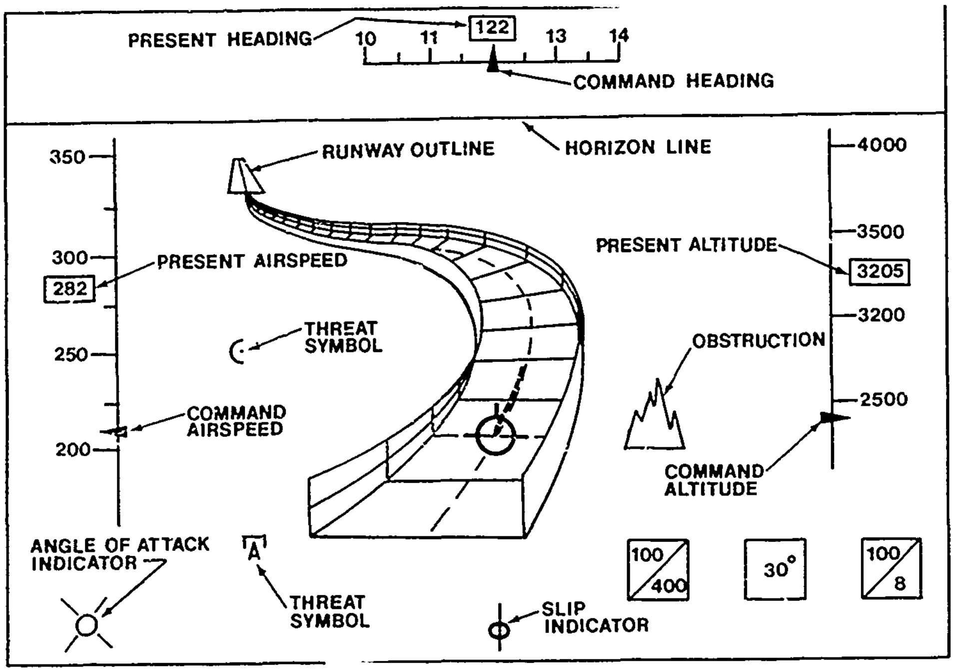


Figure 18d. Proposed Flight Path Display: Aircraft is Shown Above and Slightly to Left of Command Path, Banking Slightly to the Right to Attempt to Intercept the Path Laterally.

The option of including a textured surface, with sky, horizon line and ground would be available, should the pilot desire this type of information. As the channel turns, or banks, the horizon line (and accompanying ground/sky texture) would bank also, in conjunction with the path. Radar-detected obstructions or threats may be indicated on the display per the pilot's command. Finally, a runway outline would appear on the display at the end of the channel during the approach and landing modes. The outline of the runway would become proportionately larger as the pilot approached touchdown, and the outer edges would stream by his view once he reached the runway, approximating the view seen by a pilot landing VFR.

The described conceptualized flight path display is proposed for future testing and evaluation as a viable replacement for contemporary cockpit displays.

APPENDIX A

ILLUSTRATIONS OF NON-FLIGHT PATH DISPLAYS USE IN REFERENCED COMPARISON STUDIES

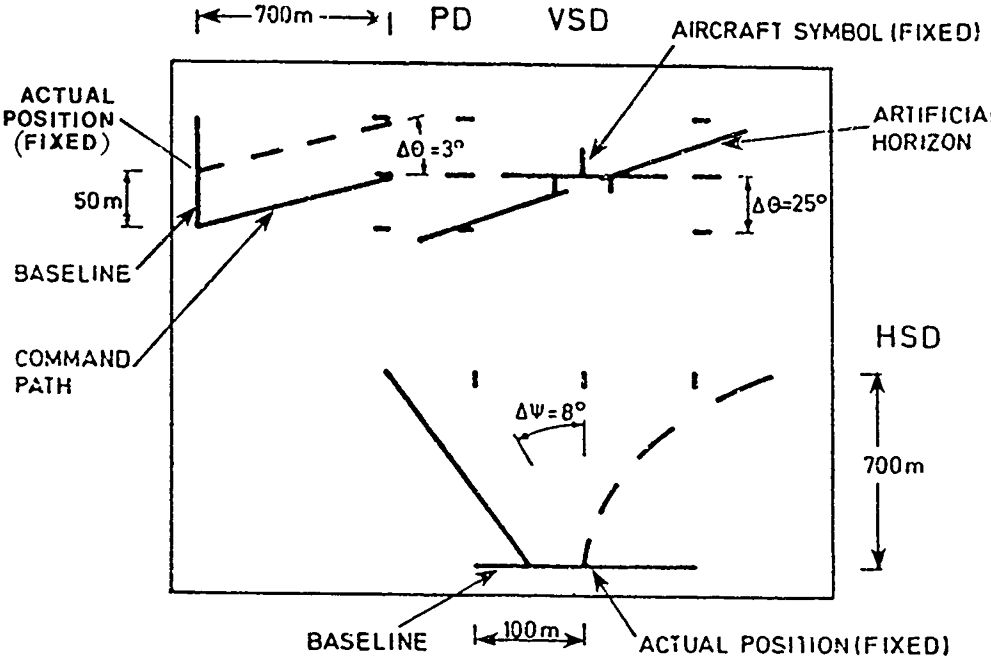


Figure A1. Kraiss and Schubert: Two Dimensional Display (from "Comparative Experimental Evaluation of Two-Dimensional and Pseudo-Perspective Displays for Guidance and Control", K. F. Kraiss and E. Schubert, Research Institute for Human Engineerig, Buschstrausee, Germany, November 1976).

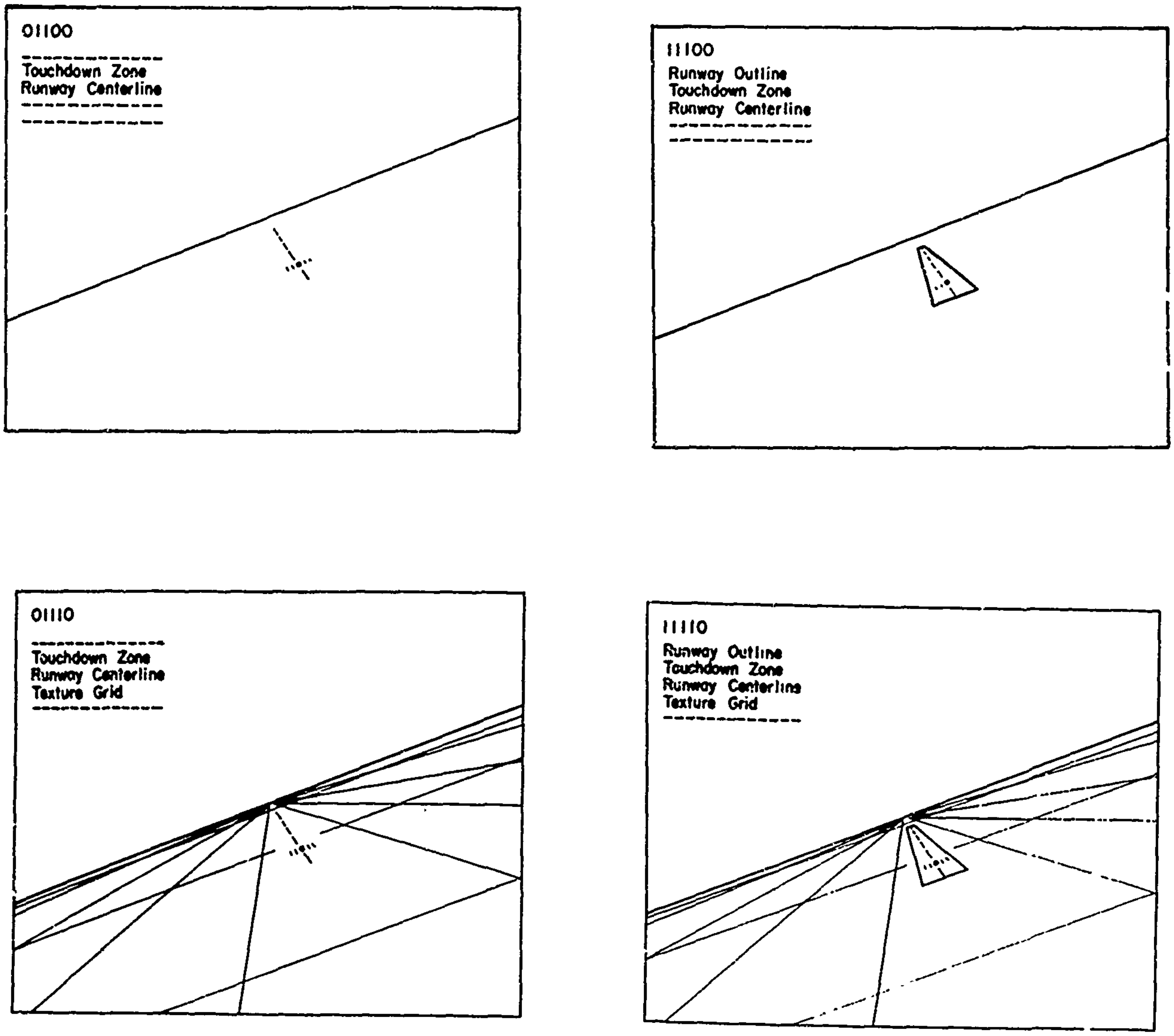


Figure A2. Eisele, Willeges and Roscoe: Non-Pathway Display Configurations (from "The Isolation of Minimum Sets of Visual Image Cues Sufficient for Spatial Orientation During Aircraft Landing Approaches", J. E. Eisele, R. C. Willeges, S. N. Roscoe, Aviation Research Laboratory, University of Illinois at Urbana-Champaign, Savoy IL, November 1976).

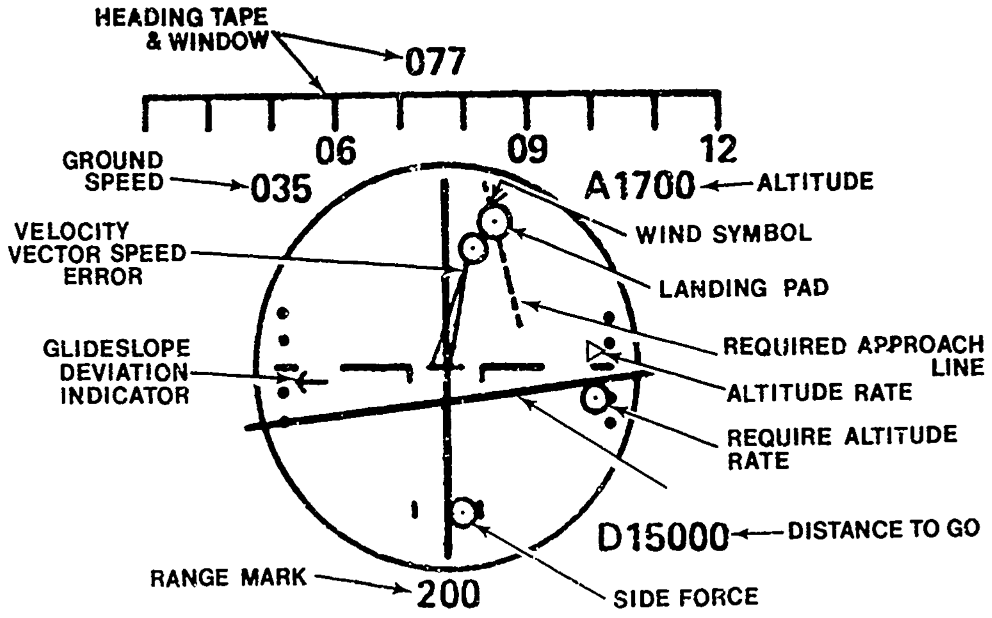


Figure A3. Murphy, McGee, Palmer, Paulk and Wempe: RAE Display (from "Simulator Evaluation of Three Situation and Guidance Displays for V/STOL Zero-Zero Landings", M. R. Murphy, L. A. McGee, E. A. Palmer, C. H. Paulk and T. E. Wempe, NASA Ames Research Center, Moffett Field CA, April 1974).

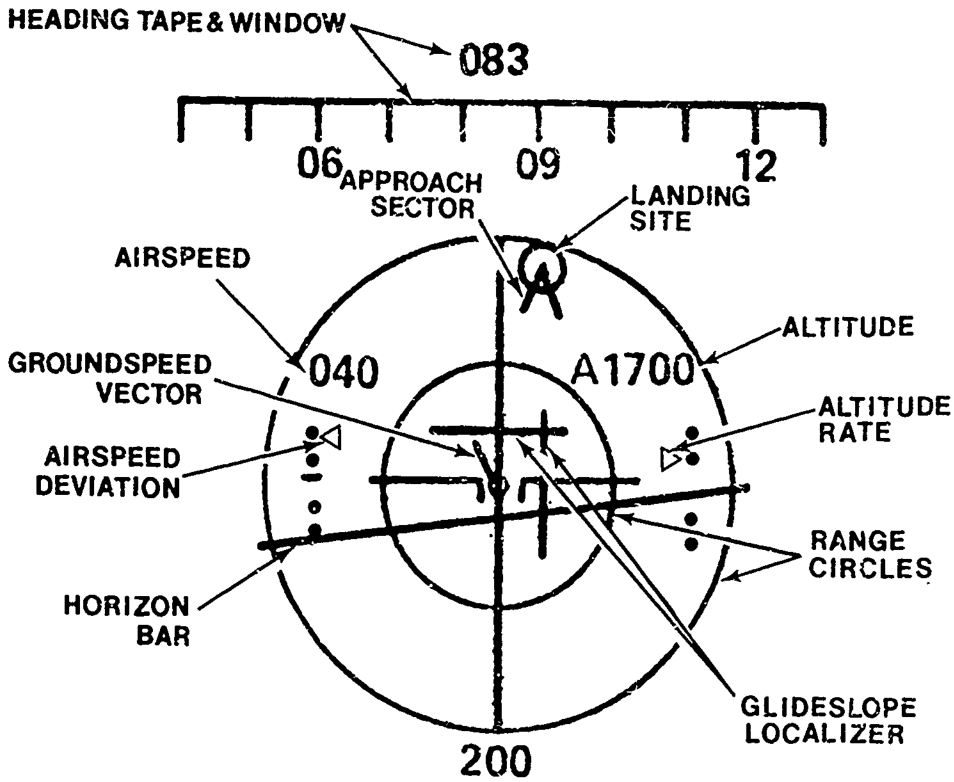


Figure A4. Murphy, McGee, Palmer, Paulk and Wempe: TELDIX Hover Display (from "Simulator Evaluation of Three Situation and Guidance Displays for V/STOL Zero-Zero Landings", M. R. Murphy, L. A. McGee, E. A. Palmer, C. H. Paulk and T. E. Wempe, NASA Ames Research Center, Moffett Field CA, April 1974).

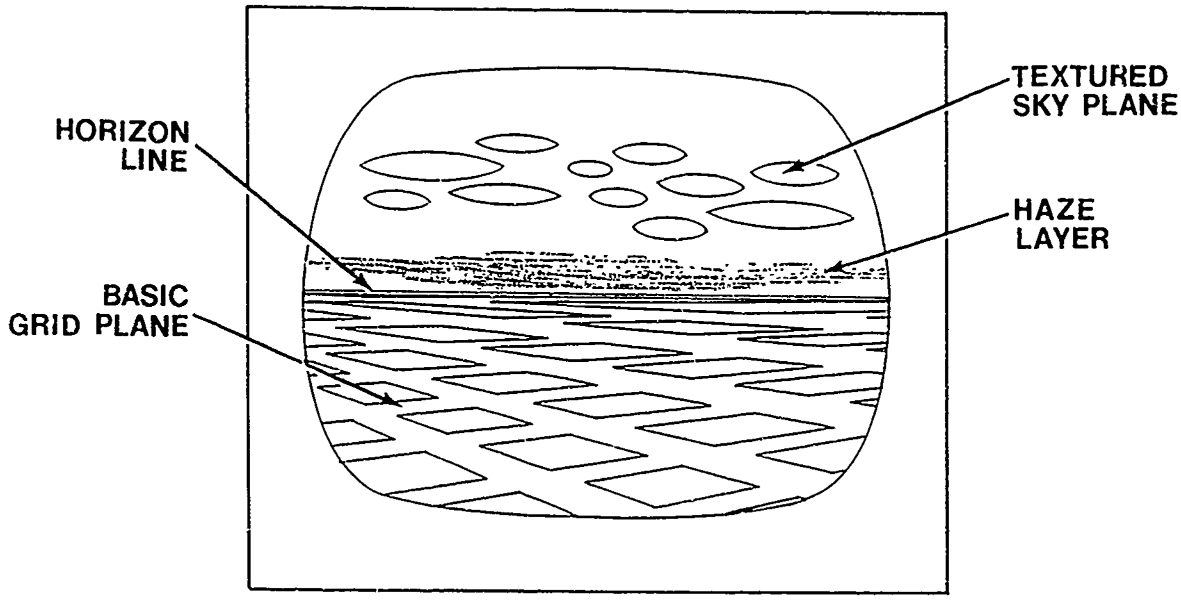


Figure A5. Sgro and Dougherty; Emery and Dougherty: Grid Plane Display (from "Contact Analog Simulator Evaluations: Hovering and Air Taxi Maneuvers", J. A. Sgro and D. J. Dougherty, Bell Helicopter Co., Report No. D228-421-016, Fort Worth TX, December 1963).

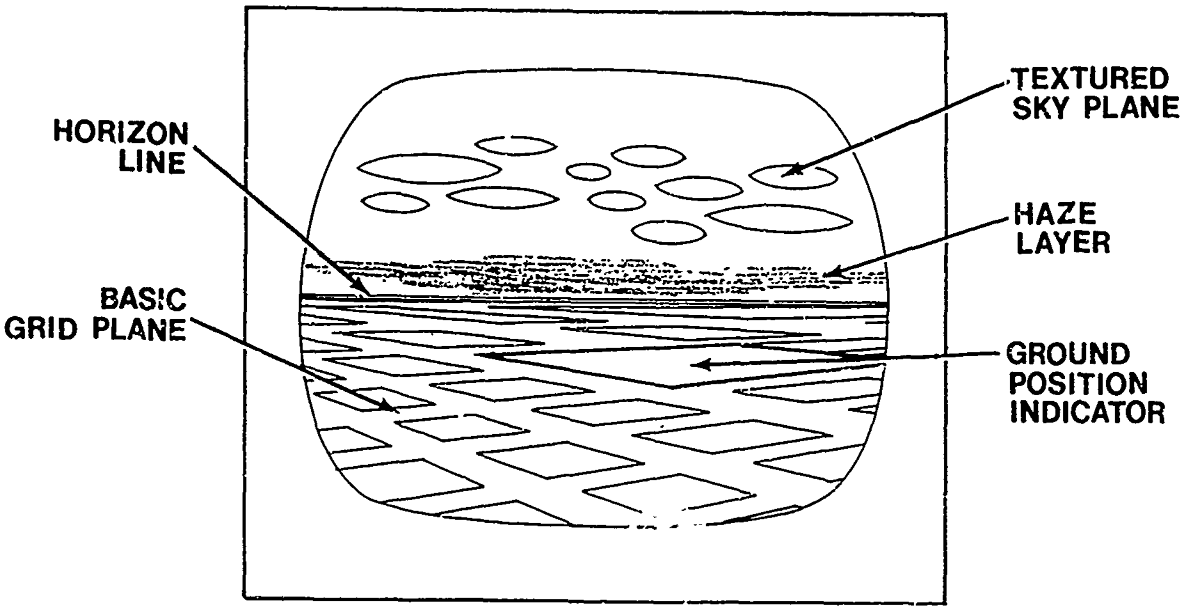


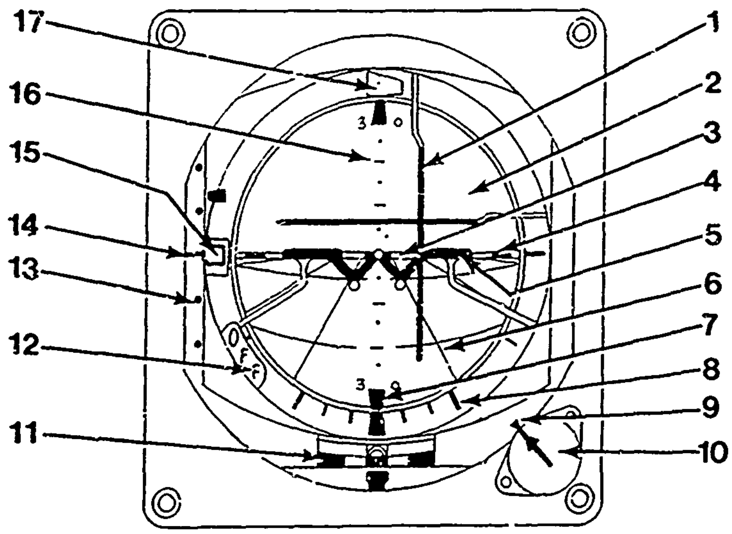
Figure A6. Sgro and Dougherty; Emery and Dougherty: Grid Plan Plus Ground Position Indicator (GPI) Display (from "Contact Analog Simulator Evaluations: Hovering and Air Taxi Maneuvers", J. A. Sgro and D. J. Dougherty, Bell Helicopter Co., Report No. D228-421-016, Fort Worth TX, December 1963).

APPENDIX B

EXAMPLE ILLUSTRATIONS OF CURRENT COCKPIT DISPLAYS

ADI

1. Bank Steering Bar
2. Attitude Sphere
3. Pitch Steering Bar
4. Horizon Bar
5. Miniature Aircraft
6. Ground Perspective Lines
7. Bank Pointer
8. Bank Scale
9. Pitch Trim Index
10. Pitch Trim Knob
11. Turn and Slip Indicator
12. Attitude Warning Flag
13. Glide Slope Deviation Scale
14. Glide Slope Warning Flag
15. Glide Slope Indicator
16. Pitch Reference Scale
17. Course Warning Flag



HSI

18. Upper Lubber Line
19. Course Selector Window
20. Course Arrow (Head)
21. Course Deviation Indicator
22. Bearing Pointer (Tail)
23. Aircraft Symbol
24. Heading Marker
25. Course Set Knob
26. Lower Lubber Line
27. Heading Set Knob
28. Compass Card
29. Course Arrow (Tail)
30. Bearing Pointer
31. TO-FROM Indicator
32. Course Deviation Scale
33. Range Indicator and Warning Flag

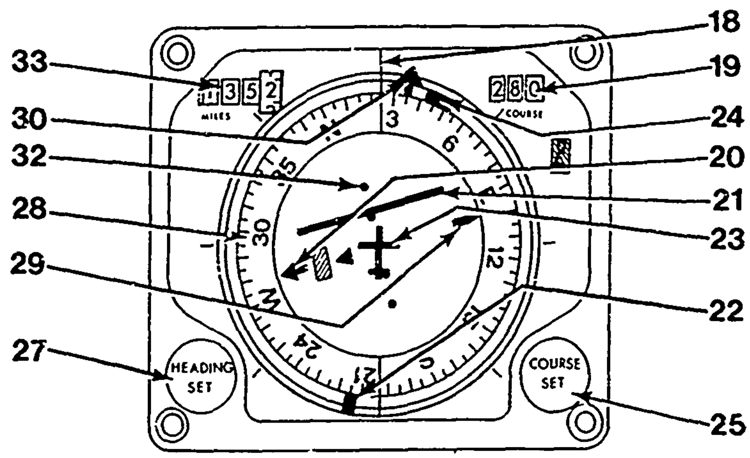


Figure B1. Flight Director System: Attitude Director Indicator/ Horizontal Situation Indicator (ADI/HSI).

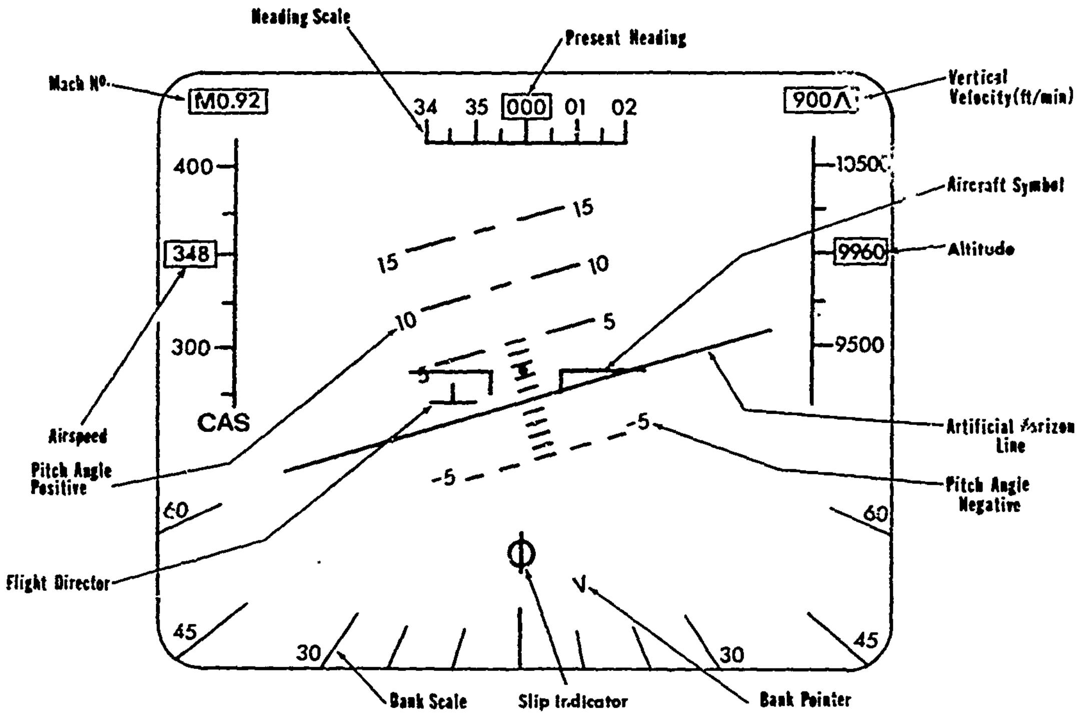


Figure B2. Electronic Attitude Director Indicator (EADI).

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UNCLASSIFIED TITLE

FLIGHT PATH DISPLAYS.

ABSTRACT

(U) AIRCRAFT DISPLAY TECHNOLOGY HAS ADVANCED TO THE STATE WHERE THE FLIGHT PAT
BOTH THE VERTICAL AND HORIZONTAL PATH ARE GRAPHICALLY REPRESENTED--IS FEASIBLE
DESIGN FLIGHT PATHS FOR USE IN BOTH FIXED WING AND ROTARY WING AIRCRAFT. RESUL
PATH AND NON-FLIGHT PATH DISPLAYS ARE DISCUSSED AND CONCLUSIONS DRAWN WITH RES
HYPOTHETICAL FLIGHT PATH DISPLAY DESIGNED AS A RESULT OF THE FINDINGS IN THE R
TESTING AND EVALUATION. (AUTHOR)

INDEX TERMS ASSIGNED

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DISPLAY SYSTEMS — FLIGHT PATHS
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PATHS — VERTICAL ORIENTATI

TERMS NOT FOUND ON NLDB

AIRCRAFT DISPLAY TECHNOLOGY — COMPARISON EVALUAT
DISPLAY SYMBOLOGY — INTEGRATED FORMAT
NON-FLIGHT PATH DISPLAYS — REFERENCED STUDIES

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ADVANCED TO THE STATE WHERE THE FLIGHT PATH DISPLAY--AN INTEGRATED FORMAT ON WHICH
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